

# UNCLASSIFIED

AD NUMBER
AD481076
NEW LIMITATION CHANGE
TO Approved for public release, distribution unlimited
FROM Distribution authorized to U.S. Gov't. agencies and their contractors; Foreign Government Information; JAN 1966. Other requests shall be referred to British Embassy, 3100 Massachusetts Avenue, NW, Washington, DC 20008.
AUTHORITY
MOA Notice 15 Jun 1966

THIS PAGE IS UNCLASSIFIED

TR 66008

JANUARY

1966



ROYAL AIRCRAFT ESTABLISHMENT

TECHNICAL REPORT No. 66008

# THE DEVELOPMENT OF A SMOOTH BORE GUN FOR THE PROJECTION OF BIRD CARCASSES

by

D. A. Perfect

THE RECIPIENT IS WARNED THAT INFORMATION  
CONTAINED IN THIS DOCUMENT MAY BE SUBJECT  
TO PRIVATELY-OWNED RIGHTS.

RECEIVED  
ROYAL AIRCRAFT ESTABLISHMENT  
1 JAN 1966

MINISTRY OF AVIATION  
FARNBOROUGH HANTS

U.D.C. No. 623.421.7 : 598.2

ROYAL AIRCRAFT ESTABLISHMENT

Technical Report No.66008

January 1966

THE DEVELOPMENT OF A SMOOTH BORE GUN FOR THE  
PROJECTION OF BIRD CARCASSES

by

D. A. Perfect

SUMMARY

A smooth bore gun apparatus has been designed and developed for the projection of bird carcasses of up to 4 lb weight at stationary targets. The apparatus is intended to provide basic information, and also to provide a testing facility, for the design of aircraft windscreens capable of withstanding the impact of birds during flight.

Full details are given of the design basis of the gun and its associated equipment, and of its present performance.

Departmental Reference: ME.428

CONTENTS

	<u>Page</u>
1 INTRODUCTION	3
2 CHOICE OF METHOD	3
3 DESIGN BASIS	5
3.1 A simple performance theory	5
3.2 Estimation of correction factor	6
3.3 Estimation of gun barrel size	7
4 DESCRIPTION OF THE APPARATUS	7
4.1 The gun	7
4.2 The firing system	8
4.3 The air charging system	9
4.4 The projectile	10
4.5 Velocity measurement	12
4.6 Safety precautions	14
5 DEVELOPMENT	15
5.1 Performance	15
5.2 Comparison with theory	16
6 FACILITIES AVAILABLE	17
7 FUTURE DEVELOPMENT	18
Acknowledgments	19
Appendix A The double bursting disc system	20
Appendix B The internal valve system	23
Appendix C Safety tests	25
Table 1 Predicted performance of R.A.E. gun	29
Table 2 Estimation of correction factor for R.A.E. gun	29
References	30
Illustrations	Figures 1-18
Detachable abstract cards	

## 1 INTRODUCTION

The design of aircraft transparencies to resist penetration by bird impact was, until comparatively recently, based on empirical formulae<sup>1</sup> derived from tests made at impact speeds up to 450 mile/h. Since extrapolation of these empirical formulae to speeds applicable to transonic aircraft was considered to be unjustified, the need was shown for a test facility for investigating bird impact on transparencies at speeds up to at least 1100 ft/sec (750 mile/h). Further, although the facility was primarily intended for work on transparencies, it was realised that there would probably be a future requirement for testing other parts of the aircraft structure.

As a result of a study<sup>2</sup> of a number of possible methods of making such experiments, the decision was made to develop a smooth bore gun suitable for the projection of a bird carcass of up to 4 lb in weight at velocities of up to 1100 ft/sec against a stationary target.

This report describes the main reasons for the choice of a smooth bore gun apparatus, the design basis for the gun, the development of the associated equipment, and the performance of the facility as it is used at present.

## 2 CHOICE OF METHOD

In assessing the various methods, the following test requirements were adopted:-

- (a) Impact speeds up to 1100 ft/sec with accurate speed control.
- (b) A standard bird weight of 4 lb, but with provision for lighter birds.
- (c) Accurate control of the point of impact on the transparency.
- (d) Provision for control of the transparency temperature.

The test methods considered were:-

(a) Transparency on sled The transparency is mounted on a sled propelled by rockets along a rail and strikes a bird carcass which is suspended on a light string frame at a suitable position over the rail.

(b) Bird on sled The bird carcass is mounted on a sled propelled by rockets along a rail. An arresting or deflecting device for the sled, or a catapulting device, allows the bird to separate from the sled and proceed on its own to strike a stationary transparency.

(c) Smooth bore gun The bird carcass is wrapped in a cloth bag and fired by means of a smooth bore gun at a stationary transparency.

The transparency on sled method offers the advantages of an unlimited choice of bird size, and a controlled strike position could be ensured. The required maximum speed could be obtained, together with lower speeds, by using appropriate combinations of rockets and sled weightings on the Pendine or R.A.E. rocket tracks. The disadvantages are that the accelerations could be excessive for the transparency attachments (up to 40 g), control of transparency temperature would be difficult and deceleration effects on damaged test specimens would be difficult to assess. In the case of the Pendine track there would be problems of track availability, and those associated with working away from the R.A.E. In the case of the R.A.E. track, considerable capital outlay would be required to bring the track to a suitable condition, and there would be a noise problem. The cost of rockets for operating at the top speed was estimated at £200 per shot at Pendine and £300 per shot at R.A.E.

The bird on sled method offers the advantages of unlimited choice of bird size; the required speeds can be achieved, and the transparency temperature can be controlled. The disadvantages are that accurate aiming possibilities may not be good; problems of availability and working away from base would apply to the Pendine track, and similar problems to those of the windscreen on sled method would apply for the use of the R.A.E. track. The cost per shot would be reduced since the sled weight would be considerably less, and an estimate of rocket cost of £40 to £80 per shot was made.

The smooth bore gun has the advantages of good speed control; accurate aiming; transparency temperature control; cheapness of operation; installation at the R.A.E. and almost unlimited restriction on specimen size or shape. The disadvantages are that an initial capital outlay would be required; the gun would be designed for a maximum bird carcass size (i.e. weight); the use of lighter birds would not be possible without some development effort; and the maximum speed would be limited to around 1000 ft/sec for an air operated gun.

In the case of both the "transparency on sled" and "bird on sled" methods, the bird could be arranged to be in a flying attitude (i.e. wings spread), whereas with the smooth bore gun the bird is made into a compact slug, and this might appear to be a more severe test method. However, tests<sup>3</sup> have indicated that  $MV^3$  is constant, where M is the bird mass and V is penetration velocity. Penetration velocity is therefore proportional to the cube root

of the mass. In a bird the wing weight is small, and about 90 per cent of the mass is in the central slug of head, body and legs. Since the cube root of 0.9 is only 3 per cent different from the cube root of 1, it is unlikely that any significant difference in penetration speed would be observed between tests using both methods.

Of the methods discussed, the smooth bore gun method appeared the most attractive, and in 1959 the decision was made to install such a test facility at the R.A.E. The design work was completed by early 1960, and the commissioning tests were commenced in May 1961.

### 3 DESIGN BASIS

#### 3.1 A simple performance theory

It is assumed that air stored initially at a pressure  $p_1$ , in a reservoir of volume  $v_1$  attached to a gun barrel of length  $L$  and cross-sectional area  $A$ , propels the projectile by expanding adiabatically along the barrel. Considering the equation of motion of the projectile of weight  $M$  when it has travelled a distance  $s$  along the barrel and the internal pressure has reached a value  $p_2$ , the opposing pressure has a value  $p_o$  and the projectile has a velocity  $u$ :-

$$\left(\frac{M}{g}\right)u \frac{du}{ds} = (p_2 - p_o) A \quad (1)$$

$$\text{and} \quad p_2 = \frac{p_1 v_1^\gamma}{v_2^\gamma} = \frac{p_1 v_1^\gamma}{(v_1 + AS)^\gamma} \quad (2)$$

$p_o$  is the opposing air pressure having a minimum value equal to atmospheric pressure, but at high projectile speeds it will be increased due to ram effects. For simplicity  $p_o$  will be taken as constant and equal to atmospheric pressure. Then from (1) and (2)

$$\int_0^{V_C} u \, du = \left(\frac{gA}{M}\right) \int_0^L \left[ \frac{p_1 v_1^\gamma}{(v_1 + AS)^\gamma} - p_o \right] ds \quad (3)$$

where  $V_C$  is the velocity after travelling distance  $L$ , i.e. the theoretical muzzle velocity.

Integrating gives:

$$V_C^2 = \frac{2gAL}{M} \left[ p_1 C - p_o \right] \quad (4)$$

where

$$C = \frac{k}{(\gamma - 1)} \left[ \frac{\left(1 + \frac{1}{k}\right)^{\gamma - 1} - 1}{\left(1 + \frac{1}{k}\right)^{\gamma - 1}} \right]$$

and

$$k = \text{reservoir volume/barrel volume}$$

$$= v_1/AL$$

The actual muzzle velocity is  $V_a$ , where

$$V_a = RV_C$$

and  $R$  is a correction factor which varies with speed and gun design.

### 3.2 Estimation of correction factor

Information<sup>3</sup> on the performance of a smooth bore gun at the C.A.A. Technical Development Centre, U.S.A., was used to calculate a value for the correction factor  $R$ . This gun had a bore of 6 in, a barrel length of 42 ft, a storage volume of 12 ft<sup>3</sup> and fired a 4 lb projectile. Using these values,  $k = 1.46$ , and hence  $C = 0.68$  and equation (4) reduces to

$$V_C = 138.3 [0.68 p_1 - 15]^{\frac{1}{2}} \text{ ft/sec} \quad (5)$$

where  $p_1$  is measured in lb/in<sup>2</sup> absolute.

Values of  $V_a$  obtained from the gun were compared with values of  $V_C$  calculated from equation (5) by inserting the appropriate values of  $p_1$ , and values of  $R$  were obtained as tabulated below:-

$p_1$ lb/in <sup>2</sup> gauge	$p_1$ lb/in <sup>2</sup> absolute	$V_C$ ft/sec	$V_a$ ft/sec	$R = V_a/V_C$
8	23	138	147	1.065
110	125	1160	763	0.658
230	245	1700	917	0.539



From the plot of  $R$  against  $V_a$  in Fig.1, it can be seen that extrapolation of results up to 1100 ft/sec is not warranted. There may be a rapid fall of the value of  $R$  as the speed of sound in air is approached, and at 1000 ft/sec a value of  $R$  between 0.4 and 0.5 could be expected.

Also in Fig.1 is plotted  $R$  against  $V_c$ .

### 3.3 Estimation of gun barrel size

Using the relationship  $V_c = V_g/R$ , equation (4) can be rearranged as:

$$L = \frac{MV^2}{2gAR^2} [p_1 C - p_0] \quad (6)$$

Assuming a gun of 6 in bore, a value of  $k = 3.0$  and a projectile weight of 4 lb, the barrel length to give an actual velocity of 1000 ft/sec from equation (6) becomes

$$L = 2200/R^2 (0.82 p_1 - 15) \text{ ft} \quad (7)$$

for  $p_1$  in lb/in<sup>2</sup> absolute.

It was proposed that the projectile carcass backing block would be formed from a material having a compressive strength in excess of 300 lb/in<sup>2</sup> and therefore the maximum operating pressure of the reservoir was taken as  $p_1 = 315$  lb/in<sup>2</sup> absolute. Using this value of  $p_1$ , the required barrel length can be calculated to be 57 ft for  $R = 0.40$  and 45 ft for  $R = 0.45$ . A barrel length of 55 ft was accepted as a reasonable compromise based on a pessimistic value of  $R$ , and the gun design was therefore based on a 6 in bore gun with a 55 ft barrel, requiring therefore a reservoir volume of

$$\begin{aligned} v_1 &= kAL \\ &= 3 \times 0.196 \times 55 \\ &= 32.3 \text{ ft}^3 \end{aligned}$$

For reasons of convenience in the gun design the reservoir volume was increased to 33 ft<sup>3</sup> and the barrel length was reduced to 50 ft with an additional extension tube of 10 ft which could be fitted if required.

## 4 DESCRIPTION OF THE APPARATUS

### 4.1 The gun

4.1.1 The gun barrel This is a smooth bore tube, approximately 50 ft long and 6 in internal diameter. It is made in flanged sections bolted

together, two being 20 ft in length, and the final section, nearest the target, being 10 ft long. An additional 10 ft section was provided should the extra length be found necessary, but has not been used. Great care was taken during the boring and assembly of the tubes to ensure that there were no discontinuities at the joints. The barrel is supported along its length by triangular steel support frames, fixed at their base to concrete plinths. Fig.2 shows the gun barrel in relation to the rest of the range area.

4.1.2 The air reservoir This is a cylinder, of 31 in. outside diameter, and having a parallel length of 69 in. The rear end is closed by a blanking plate, and the forward end carries a cone adaptor which, in a length of 28 in, reduces the diameter from that of the reservoir to that of the barrel. The reservoir is supported on a massive steel structure which is secured to a concrete slab. The internal volume of the reservoir is 33 ft<sup>3</sup>.

4.1.3 The breach mechanism This is the means whereby the projectile is loaded into the gun, and it is situated immediately at the end of the barrel nearest to the air reservoir. It consists of a large cylindrical block of metal, bored to the internal diameter of the gun barrel, and rotating in a housing. It has two positions into which it can be locked by means of a safety pin. In the "FIRE" position the bore of the breach lines up with that of the barrel, and thus air discharged from the reservoir has a free passage down the gun barrel. If the breach is rotated through 90° into the "LOAD" position, the gun barrel is sealed off from the reservoir, and the bore of the breach block lines up with holes in the outer casing of the breach. A projectile can thus be inserted into the breach which, at the appropriate time, is rotated to the "FIRE" position. Fig.3 shows the air reservoir, the breach mechanism, and also the disc holder (see Appendix A).

#### 4.2 The firing system

4.2.1 Two firing systems for the gun were considered, (a) a plunger type valve mechanism inside the air reservoir, operated on a servo system using an electrically operated firing valve, and (b) a double bursting disc system. Although the final choice of firing system fell to the internally mounted valve, difficulties in manufacture resulted in an inordinate delay, and the bursting disc system was introduced as a temporary expedient. Fig.4 shows the components of this system. In practice, this bursting disc system proved to be sufficiently reliable and flexible so that, even when the manufacture of the parts of the valve was completed, it was decided that the delay to the

test programme that would result by the opening up of the reservoir and the installing of the valve was not justified. Thus, for approximately the first two years of its life, the gun was fired by means of bursting discs.

4.2.2 The opportunity was taken, during the first major overhaul of the facility, to install the internal valve, and a considerable amount of time was spent on development of the system. Although, in theory, the valve system is more flexible and considerably safer than the disc system, in practice it was found that a great deal of development time, and a number of modifications were necessary to make the valve system work at all. Further, once it was working satisfactorily, a great deal of maintenance work was necessary to ensure consistent results. It was assumed that this was due to the high speeds of acceleration and deceleration of the piston, and the consequent short life of the 'O' ring seals which were of major importance in maintaining consistency. These problems were never satisfactorily overcome, and it was decided that the work involved in continually checking the system, and also the dangers of a sudden change in gun performance during an important test, were such as to render the whole system unsatisfactory. Thus a change back to the bursting discs was made, and this is now the standard firing system of the facility.

4.2.3 A full description of the bursting disc system is given in Appendix A, and a brief description of the valve system is given in Appendix B.

#### 4.3 The air charging system

4.3.1 The air supply for the operation of the gun is provided by a Broom and Wade TN.20 compressor, housed in a sound insulated compartment in the gun building. This compressor has a maximum working pressure of  $450 \text{ lb/in}^2$ , a stroke of 3 in, works at 600 rev/min, and delivers air at a rate of  $13 \text{ ft}^3/\text{min}$  of free air. When in use with the facility, it increases the pressure in the reservoir by  $50 \text{ lb/in}^2$  in approximately 8 minutes.

4.3.2 A diagrammatic representation of the system is given in Fig.5, and from this it can be seen that each part of the system can be charged separately, gauges being provided to register the pressure in each stage. The air in any part of the system can also be discharged by means of exhaust valves.

4.3.3 When used with the double bursting-disc method of firing (see Appendix A) the procedure is as follows. With all other valves closed, the reservoir and firing bottle valves are opened, and the pressure in these starts to rise. Since the bursting discs are domed, it is essential that the pressure in the interspace should never exceed that of the reservoir, a situation which

would arise (due to the great difference in volumes) if the two were charged simultaneously. Hence it is usual to allow the reservoir pressure to build up to about  $10 \text{ lb/in}^2$  before the interspace valve is opened, and then by suitable manipulation of this valve to maintain this lead during the charging process. As soon as the interspace reaches its correct pressure the valve is closed, and charging of the reservoir and firing bottle continues. When the reservoir is up to pressure the compressor is switched off, and all valves closed. The final "topping up" of the firing bottle is done from a standard compressed air cylinder stored outside the gun building, and controlled by a valve through a reducing valve.

4.3.4 In order to achieve maximum accuracy of the pressure readings, more than one gauge is used in the major circuits. Thus, for the reservoir three gauges are provided. For very small pressures, the  $0 - 80 \text{ lb/in}^2$  gauge is used; for intermediate pressures the  $0 - 200 \text{ lb/in}^2$  gauge is used, and for pressures in excess of this the final gauge has a range of  $0 - 500 \text{ lb/in}^2$ . In the case of the interspace, since the pressures used are approximately half those of the reservoir, two gauges are provided viz  $0 - 80 \text{ lb/in}^2$  and  $0 - 200 \text{ lb/in}^2$ . For the firing bottle, since this pressure does not have to be particularly accurate, only a  $0 - 500 \text{ lb/in}^2$  gauge is provided. As the pressure in each part of the circuit rises to approach the maximum of a particular gauge, that gauge can be isolated by means of a valve, and the reading transferred to the next gauge in that circuit.

4.3.5 Every gauge is provided with a "snubber" so as to prevent damage to the gauge when the gun is fired and the pressure is suddenly released.

4.3.6 The valves controlling the charging and exhausting of each part of the system, together with the appropriate pressure gauges, are conveniently grouped on the control console, which is shown in Fig.6.

#### 4.4 The projectile

4.4.1 Although the gun was originally designed solely for use with a 4 lb projectile, development work since has resulted in a capability also to fire projectiles weighing  $2\frac{1}{2} \text{ lb}$  and  $1 \text{ lb}$ .

4.4.2 The standard 4 lb projectile This consists of three elements - a chicken, a plug, and a containing bag. These are shown in Fig.7. The chickens used are freshly killed immediately before delivery (in small batches) to R.A.E., where they are transferred to a deep freeze cabinet after being weighed, the weight being stipulated as being in the range  $3\frac{1}{4}$  to  $3\frac{1}{2} \text{ lb}$ . As

each bird is required, it is removed from the deep freeze and allowed to regain room temperature naturally over about 24 hours. The plug is cylindrical in shape, four inches long and of diameter slightly less than that of the bore of the gun. It is made of an expanded plastic material, weighs approximately 7 oz, and its purpose is to ensure that the projectile is a good fit in the barrel of the gun, thus ensuring consistent results. The bag is made of metallised nylon material, and is properly shaped so that the closed end is rounded, and the open end has a draw string through a hem, by means of which this end can be closed and secured. The purpose of the bag is to ensure that the projectile is intact when it reaches the target, since without it the chicken would be broken up completely by air blast during its passage from the gun to the target during high speed tests. In preparing the projectile, each individual part is weighed immediately before assembly. The chicken is then placed in the bag, head first, and its legs carefully folded round the body. If the total weight of the components comes to less than 4 lb, then a small amount of wet rag, sufficient to bring the total weight up to this value, is placed in the bag with the chicken. The diameter of the selected plug is carefully checked. Originally it was believed that the material of the plug was stable and that its finished diameter would be that of the mould in which it was expanded. Experience has shown however that shrinkage does take place for some time after delivery, and this was thought to be a big factor in the scatter of velocity obtained for a given pressure in the early firings. The present practice is to have the plugs coming from the mould slightly larger than the diameter found to be satisfactory, and then, if necessary, taking a small skim off each one to bring it down to the required diameter. The checked plug is inserted in the bag on top of the chicken, and the open end of the bag is closed and secured by means of the draw-string. The projectile is now ready for insertion into the breach. The complete projectile is shown in Fig.8.

4.4.3 The standard  $2\frac{1}{2}$  lb projectile This is very similar in make-up to the standard 4 lb projectile, with the exception that the chicken used is a smaller one, and weighs approximately 2 lb. The method of assembly of the component parts of this projectile is identical with that used for the 4 lb projectile.

4.4.4 The standard 1 lb projectile In order to cater for the firing of birds weighing as little as 1 lb, a completely new approach to the design of the projectile had to be made. In the case of the bigger projectiles, the foamed plastic plug was a part of the actual projectile, and its weight was a part of

the total weight of the projectile. This was accepted as being satisfactory. With the 1 lb projectile however, the weight of the backing plug would have been at least 50% of the total weight of the projectile, and this was thought to be unacceptable. A "sabot" system was thus developed. The sabot, made of the same material as the backing plug, is slightly smaller in diameter than the bore of the gun barrel, and is 11 in long. It has an annular recess in one end, 4 in diameter and 7 in deep. The bird used in this case is a pigeon, which weighs approximately 1 lb. If any bird is found to be under this weight then, as before, a small amount of wet rag is used to bring the weight up. The bird carcass is placed into the same type of nylon bag as used with the larger projectiles, and the spare bag folded over and tied. It is then inserted tail first into the recess in the sabot, which is placed in the breach of the gun so that the bird is facing the open end of the barrel. The muzzle end of the barrel has bolted to it a heavy metal plate which has a  $4\frac{3}{4}$  in hole drilled centrally through it. (This orifice plate is only fitted for tests with 1 lb birds.) Thus, on firing the gun, the sabot with the bird in place, is propelled down the gun barrel and on striking the stopping plate, the bird continues on its trajectory, but the sabot is retained in the barrel. The thin walls of the sabot round the central hole usually break up on impact, but the particles are so small that, even if they reach the target, which is very doubtful, they cause no damage to it. The solid base of the sabot is invariably retained in the barrel and has to be removed by firing the gun again once the stopping plate is removed, and the target area cleared.

#### 4.5 Velocity measurement

4.5.1 Although the velocity of the projectile can be deduced approximately from the pressure used in each case, an accurate determination of the velocity of impact of each firing is considered essential. A considerable amount of time, therefore, was spent in trying various methods before the final system was adopted. The aim was to evolve a method of measuring velocity which was simple, accurate, repeatable, reasonably robust for range work, and which did not suffer from the disadvantage of being prematurely triggered by stray currents or atmospheric conditions. The various methods tried included the following:

- (a) Photo-electric cells ("sky screens") used in conjunction with a micro second counter through amplifying equipment.
- (b) Photo-electric cells used in conjunction with a Cintel recorder giving a permanent record on paper.

- (c) Breaking wires used in conjunction with a Cintel recorder.
- (d) Shorting wires used in conjunction with a Cintel recorder.
- (e) Breaking wires used in conjunction with a Chronotron.

All the "electronic" methods, i.e. (a) to (d) above, were found to suffer from major disadvantages for this type of work. The final method selected was the one employing breaking wires together with a Chronotron, and this method has been used throughout the firing programme to date, and has proved most reliable and consistent.

4.5.2 In order to carry the breaking wires, a special "timing stand" was built. This was designed to stand on the main longitudinal beams of the target area, and could thus be moved, forwards or backwards, according to the size of the specimen being tested and yet remain properly aligned between gun and target. In use, the stand is moved as near the test specimen as possible so that the velocity recorded is virtually the striking velocity of the projectile. The stand is of tubular construction and of box section at the top, carried on a base which rests on, and is clamped to, the main longitudinal beams of the target area. The two ends of the box section which are in the line of fire are open, and thus the projectile travels down the length of the box on its flight between gun and target. The top and bottom cross members at each end of the timing stand carry terminal blocks between which is stretched the lengths of breaking wire, which thus are in the vertical plane and at right angles to the path of the projectile. The two wires are 5 ft apart. The terminal blocks are in turn connected by cables running the length of the range to the gun building, where they connect to the Chronotron. The cables are normally run out, connected up and tested just prior to a firing of the gun, and taken in again immediately the test is over, thus minimising the risk of water causing electrical interference and influencing the results. The timing stand is shown in Fig.9.

4.5.3 The breaking wire used throughout was oxydised nichrome wire, of 0.003 in diameter. This wire has a considerable degree of stretch before breaking, but this effect is overcome by ensuring that the two wires are tensioned as near equally as possible.

4.5.4 The Chronotron is a standard piece of equipment (Type 25E), and is essentially a very accurate capacitor. The breaking by the projectile of the first (or "start") wire causes a constant current to charge this capacitor, whilst the breaking of the second ("stop") wire isolates it, and the voltage developed across it is measured by a valve voltmeter directly calibrated in units of time.

Since the distance apart of the two wires is known (5 ft) the velocity can readily be determined. One drawback to the system is that the reading of the meter does gradually decay as the capacitor discharges, but this decay is very slow and presents no difficulty provided the reading is taken immediately after the firing. Secondly, the chronotron is not provided with any filter device to reject further signals, so that if, for example, the "stop" wires were to re-make contact with each other, the instrument would restart counting, and the result would be in error. For this reason great care was taken to cover the whole top part of the timing stand with electrical insulation so that should the two ends of the broken wire come into contact with the frame, no circuit could be set up that would start the chronotron again. This insulation is examined at frequent intervals to ensure that it has not been damaged by flying fragments or weathering and replaced regularly. To date, no troubles have been encountered due to this cause.

#### 4.6 Safety precautions

4.6.1 With this equipment, it is frequently necessary for personnel to enter the target area before firing takes place, but after the gun has been fully charged and is ready to fire, e.g. to remove heating apparatus etc. For this reason, adequate safeguards must be taken to ensure that the gun cannot accidentally be fired, and also cannot deliberately be fired unless and until a certain sequence of operations has been performed. These safety precautions may be divided into two groups, viz, mechanical and electrical.

4.6.2 The main mechanical safeguard is the breach mechanism. As already described in para. 4.1.3, this is rotatable from the "LOAD" position, in which the gun reservoir is sealed off from the barrel, to the "FIRE" position. Throughout the entire process of charging the gun and doing all the preliminary work, the breach is kept in the "LOAD" position and locked into this position by means of a safety pin. Thus, should there be a premature burst of the discs, the air from the reservoir would be discharged through small holes into the gun building, and the projectile would remain safely in the breach. Only at the very last minute, and as part of the firing procedure after the range has been cleared and the warning klaxon sounded, is the breach rotated to the "FIRE" position.

4.6.3 The electrical safeguards are as follows:

(a) The electro-pneumatic valve which admits high pressure air to the underspace and so fires the gun (see Appendix A) is operated by a 24 volt D.C.



battery supply. This battery is kept in a locked box, the key is held by the officer in charge of the trial, and only during the final sequence is this box unlocked, the firing lead plugged in, and the supply switch set to "ON".

(b) Even with the battery connected and the supply switch on, the firing circuit is not complete until the breach is rotated into the "FIRE" position and locked in this position by means of a safety pin which, in so doing, depresses a micro switch in the firing circuit.

(c) With the circuit completed by (a) and (b) above, pressing the firing button still will not fire the gun until a final safety link, which is also kept by the officer in charge of the trial, is inserted into a socket on the firing box. This safety link is inserted only at the instant of starting the count-down, i.e. five seconds before pressing the firing button.

4.6.4 Before any firing trials were done using this facility, some safety tests were carried out to try and assess the potential hazards, if any, to personnel in the gun building should a premature burst of a disc occur, and also to try and establish the possibilities of such a premature burst taking place. The results of these tests are given in Appendix C, and led to the conclusion that no special hazard existed.

## 5 DEVELOPMENT

### 5.1 Performance

5.1.1 Once the safety aspect of the facility had been cleared (para. 4.6.4) a series of firings was commenced in order to calibrate the equipment. In use, although a particular velocity of impact is specified, the velocity attained is not known until after the firing takes place, and hence a pressure-velocity curve is necessary in order to determine the cylinder pressure to use for a particular velocity.

5.1.2 As already stated, the first firings with 4 lb birds showed a considerable amount of scatter in velocity, particularly at the lower velocities where it amounted to approximately  $\pm 8\%$  of the mean velocity. The pressure-velocity curve given in Fig.10 is a reasonable mean through all the results that have been obtained. With more recent firings for which the plug diameter has been carefully controlled, a considerably reduced amount of scatter has been encountered, and the results fall very closely indeed to the curve. It will be noted that the pressure-velocity curve is extremely steep at its lower end, and thus an appreciable difference in velocity can result from a very small change in pressure. Consequently this area was too sensitive to small pressure

changes to be of much practical value. This difficulty was overcome by the use of "throttle plates" - discs of steel 0.38 in thick, inserted between the end of the reservoir cone and the bursting disc holder. Two different throttle plates were used, one having a 3 in dia. hole in the middle of it, and the other having a 2 in dia. hole. By using these throttle plates in this manner, the loading, charging, and firing procedures remained unaltered, but the throttle plate restricted the rate at which the air from the reservoir could act on the projectile, thus giving a reduced velocity for the same pressure. The curves relating to these two throttle plates are also shown in Fig.10. It will be seen from these curves that the lowest speed possible with this equipment is 200 ft/sec, since at pressures below 40 psi in the cylinder the necessary bursting discs become too flimsy to handle with safety. The maximum speed can be seen to be approximately 950 ft/sec. However, the top end of the speed range has not yet been sufficiently fully explored, due to lack of need of such speeds to date, to be certain that the curve is accurate in this region. Further work may result in a modification to the calibration curve at its upper limit. A single shot at a reservoir pressure of 182 psi gave a velocity of 1000 ft/sec.

5.1.3 Only a limited number of firings have taken place using  $2\frac{1}{2}$  lb projectiles. The resulting pressure-velocity curves are given in Fig.11 but, due to the limited results available, these curves are tentative. Since only low speed tests have been made with this projectile, curves associated with the 2 in and 3 in throttle plate only are available. It is interesting to note that these curves are almost identical with the corresponding curves for the 4 lb projectile.

5.1.4 Very few firings using the 1 lb projectile have been made, and the 3 in throttle plate only has been used. The pressure-velocity curve given in Fig.12 is therefore tentative only, and may require considerable modification with further experience of this type of projectile.

## 5.2 Comparison with theory

By inserting the actual values of the gun constants in equation (4) it can be expressed as:-

$$V_C = 151(0.84 p_1 - 15)^{\frac{1}{2}} \text{ ft/sec for } p_1 \text{ in lb/in}^2 \text{ absolute} \quad (8)$$

A value of R for a given value of  $V_C$  can be obtained from Fig.1, and thus a predicted value of  $V_a$  can be calculated from  $V_a = RV_C$ . These values are listed in Table 1 and plotted in Fig.13. Also plotted in Fig.13 are the

actual velocities measured for both the R.A.E. gun and the CAATDC gun. In the case of the R.A.E. gun the calibration curve of Fig.10 is used, and for the CAATDC gun the values given in para. 3.2 are taken. It can be seen that for pressures below 110 psi the gun performance is at the most 10% below its predicted performance. At reservoir pressures above 110 psi there is insufficient evidence on which to base any comments on performance, but it would appear that the performance is up to that predicted. In Table 2 the actual correction factors for the R.A.E. gun are tabulated, and Fig.14 shows a comparison of the variation of  $R$  with  $V_a$  for the two guns. From Fig.13 it can be seen that the performance of the R.A.E. gun, pressure for pressure, is better than that of the CAATDC gun, but Fig.14 illustrates that, at the lower velocities, the CAATDC gun conforms more nearly to its predicted performance than does the R.A.E. gun. One reason for this may be that the measurement of actual velocity is made some 20 ft from the gun muzzle in the case of the R.A.E. gun, whereas with the CAATDC gun it was made just beyond the end of the barrel.

## 6 FACILITIES AVAILABLE

6.1 The gun was originally designed for a research programme on materials and methods of manufacture of aircraft windcreens. The test specimens were of a standard overall size, and are assembled into a light alloy support frame which, in turn, is bolted to a heavy steel frame (the "swivel frame") which forms part of the target structure. Thus any specimen of material can be tested which can be made to fit into the standard support frame. The method of securing the specimen to the frame is by bolting, and the holes in the frame are jig-drilled. The usual procedure is that this type of specimen is supplied to R.A.E. undrilled, and then drilled to the R.A.E. jig. The swivel frame can be adjusted to give varying angles between the line of flight of the projectile and the face of the specimen. Seven such angles of incidence are available, viz  $18^\circ$ ,  $24^\circ$ ,  $30^\circ$ ,  $37^\circ$ ,  $45^\circ$ ,  $57^\circ$  and  $76^\circ$ . It is usual practice to quote the angle between the line of flight and the normal to the windscreen, and on this basis the available angles are  $72^\circ$ ,  $66^\circ$ ,  $60^\circ$ ,  $53^\circ$ ,  $45^\circ$ ,  $33^\circ$  and  $14^\circ$ . In practice, it has been found that the first two of these angles present too small a frontal area in relation to the diameter of the projectile, and are not used. The target structure and swivel frame are shown in Fig.15.

6.2 Apart from these standard specimens, a variety of other test specimens has been accommodated, ranging in size from a windscreen mounting frame to a portion of wing structure. In each case so far, it has been possible to design a mounting for the test specimen that would attach to the existing target structure,

which was used to react the major part of the loads involved. Since the gun itself is fixed, and is not capable of being trained on a particular spot of the target, the mounting must be so designed that when it is in position in the target, impact occurs at the appropriate spot. Further, should it be necessary to hit the target at more than one place, the necessary adjustment must be provided within the mounting. Fig.16 shows the available space in the target area, and Figs.17 and 18 show typical target assemblies.

6.3 Facilities are available for the pre-heating of the type of specimen described in para. 6.1. This is done by means of electric heater mats clamped on either side of the test specimen, and capable of raising the temperature from ambient to  $50^{\circ}\text{C}$  over a period of approximately 2 hours. This slow heating ensures that the temperature is uniform throughout the thickness of the specimen. Where the test specimen has vinyl, acrylic or other plastic interlayers, standard temperature sensing elements can be set in these layers during manufacture, and equipment is available for reading the indicated temperature, which is thus an internal temperature and not a surface one. Firing can take place as soon as a test specimen reaches its required temperature.

6.4 Some windscreens are heated electrically by the "gold film" method, and provision is made to enable a test specimen that has a gold film to be heated in that way. A 400 volt 3 phase A.C. supply is provided and, by means of rheostats and meters in each phase, any required voltage can be obtained. Since each phase of the supply is separately controlled, different voltages may be applied to the different phases in full simulation of a typical installation. The sensing elements incorporated into gold film windscreens can be connected to indicators in the gun building, and the windscreen under test can be maintained at a given temperature for a given length of time or, alternately, firing can take place as soon as a particular temperature is reached.

## 7 FUTURE DEVELOPMENT

The main work still to be done on the facility consists of obtaining more experience with  $2\frac{1}{2}$  lb and 1 lb bird firings, so as to enable the pressure-velocity calibration curves to be drawn with more certainty.

Although not plotted on Fig.12, a few firings using 1 lb birds and the type of sabot described in para. 4.4.4, have recently been done, without the use of any throttle plate so as to explore the higher speed ranges. The first shot gave a velocity of 800 ft/sec for a reservoir pressure of  $80\text{ lb/in}^2$ , which seemed quite feasible. A second shot at  $93\text{ lb/in}^2$  however gave a velocity of

770 ft/sec, and a third shot at 137 lb/in<sup>2</sup> gave only 715 ft/sec. Thus it was obvious that the system was not acceptable for high speed testing. Recently some tests have been made in which the stopping plate at the end of the barrel was dispensed with and the sabot was split down the middle for its full length. Thus, as before, sabot and bird are projected down the barrel together but, on emerging from the barrel, the drag of the outside air forces the two halves apart and the separate pieces fly off on either side of the target whilst the bird continues on its normal trajectory. In practice it would appear that although the half sabots diverge they also partially break up in mid air and it is possible that some small pieces do strike the target. However, the method looks very promising and its development is continuing. A speed of 1100 ft/sec has been obtained for a 1 lb bird with this split sabot method and the results so far obtained indicate that the ultimate maximum speed has not yet been reached. The lower end of the curve is even more steep than that obtaining with the standard 4 lb bird, so that it will be necessary to use throttle plates once again for the lower speeds, and to produce calibration curves relating to them.

#### ACKNOWLEDGMENTS

Far too many people have been involved in the various stages of design and manufacture of the facility to make it possible to mention them all, but the author would like to pay a special tribute to the design staff of the S.M.E. Drawing Office; the workshops of Woolwich Arsenal and of the R.A.E. In particular, the author would like to acknowledge the assistance given in the development and operation of the facility by Messrs. J. D. Booker, P. A. Keene, J. Morley, W. Cullen and B. E. Dawson.

## Appendix A

### THE DOUBLE BURSTING DISC SYSTEM

A.1 Between the breach mechanism and the cone end of the air reservoir provision is made for the insertion of a cylindrical holder, having its centre bored out to the internal diameter of the gun barrel. This holder is made in three sections which spigot into each other, the bursting discs being located between the sections of the holder. The whole assembly is then inserted into its space, and bolts, which pass through the flange of the cone and a corresponding flange on the breach, are tightened, so clamping the whole system firmly together. In the face of the holder adjacent to the cylinder is cut a groove for an 'O' ring seal to make an airtight joint. An exploded view of the components is shown in Fig.4.

A.2 In the first stages of the use of the facility, when it was believed that the disc system was an interim one only, the bursting discs were made at R.A.E. from local stocks of material of specification L16 (aluminium sheet - half hard) and had an outside diameter of 8.5 in. A series of tests was necessary to arrive at a curve showing the relationship between disc thickness and bursting pressure. Due to the scatter involved with these early discs, this curve in fact consisted of two lines, one representing the minimum bursting pressure, and the other representing the maximum bursting pressure. Thus, for any given thickness of disc, it could be determined that the bursting pressure would lie between two values. A further series of tests established that a given disc could withstand the application of 70% of its minimum bursting pressure for a considerable period of time without rupture.

A.3 The space between the two discs (the "interspace") and the gun reservoir are capable of being charged with air from a compressor, and a system of taps and pressure gauges controlling and registering the pressures in each part of the system is provided. If the interspace and reservoir are charged with air, then a pressure differential will be set up across the two discs, the value depending upon the pressure selected. The pressure differential across the front disc will be that of the pressure in the interspace, since the pressure in front of the forward disc is atmospheric. The pressure differential across the rear disc will be the difference between the reservoir pressure and the interspace pressure. The method of firing the gun is that, on pressing the firing button, an electro-pneumatic valve is opened and extra pressure from a pressurised "firing bottle", charged up as a part of the gun charging procedure, is injected into the interspace. The pressure differential across the front

disc is raised beyond the bursting value of this disc, which ruptures. This reduces the pressure in the interspace, and since the pressure in the reservoir is greater than the bursting pressure of the rear disc, this disc also ruptures and the whole volume of air in the reservoir is discharged down the gun barrel.

A.4 An example of the necessary calculations for a particular thickness of disc will illustrate the method of use:

Disc thickness 0.0178 in (i.e. nominal 26 swg)

Bursting pressures from graph 105 to 124 lb/in<sup>2</sup>

Since safety is the criterion, the minimum of these values must be used, and hence the "safe" pressure is  $0.7 \times 105$ , i.e. 73 lb/in<sup>2</sup>. Thus the interspace can be charged to 73 lb/in<sup>2</sup> with complete safety, and the reservoir pressure can be  $73 + 73$ , i.e. 146 lb/in<sup>2</sup>. This however is a maximum value for reservoir pressure, just meeting the safety requirements. A lower reservoir pressure could be used sufficient just to burst the rear disc on removal of the supporting pressure from the interspace. This must be not less than the maximum bursting pressure of the disc, i.e. 124 lb/in<sup>2</sup>. Hence for this particular disc thickness, the reservoir pressure can be anything between 124 and 146 lb/in<sup>2</sup>. This pressure range covers a reasonably wide speed range, and hence reduces the number of different thicknesses of discs that must be stocked to cover the whole speed range of the facility.

A.5 With the decision that the bursting disc system should be the standard firing method, it became uneconomic to manufacture and test the necessary discs at R.A.E., and a change was made to discs purchased from a specialist manufacturer. These had the great advantage of being much more accurate than those previously used, and advantage could be taken of the very low scatter value guaranteed for each batch of discs. Thus it was possible to use the nominal quoted bursting pressure of each disc, since 70% of the variation from the nominal became a negligible amount. Hence, with a nominal burst pressure of 100 lb/in<sup>2</sup>, the "safe pressure" is 70 lb/in<sup>2</sup>, and the reservoir pressure can be anything between 100 lb/in<sup>2</sup> and 140 lb/in<sup>2</sup>. It can be seen that this is a much wider range than in the example quoted above, and a stock of only six different types of disc was found necessary to cover the whole speed range of the facility.

A.6 A somewhat arbitrary method of determining the pressure to which the firing bottle is charged was adopted, but it has worked very well in practice and the front disc has never failed to rupture on pressing the firing button. This

pressure depends of course upon the relative volumes of firing bottle and inter-space, and for this particular case the value chosen for the firing bottle is one and a half times the bursting pressure of the front disc.

A.7 It is of course quite feasible to have the two discs of different burst values, but it is felt that there is little advantage to be gained by this, and all the tests in the facility are done using similar discs in the two positions since this reduces the risk of installing discs in the wrong order.



## Appendix B

### THE INTERNAL VALVE SYSTEM

B.1 Within the body of the air reservoir was installed a piston-type valve. This consisted of a light alloy rod running the whole length of the reservoir, and supported near each end in bearings. These bearings were carried in three-legged "spiders" which secured to the walls of the reservoir and maintained the bearings in alignment down the centre of the reservoir. Great care was necessary in the setting up of these spiders so as to ensure that the piston-rod could run smoothly and freely within the bearings. The front end of the piston-rod, forward of the first spider, carried a large, bulbous head. Included in this head was a rubber sealing ring of large section which, with the piston in its fully forward position, met the cone shaped front end of the reservoir and made an airtight seal.

B.2 The blanking plate at the rear end of the reservoir was removed, and in its place was fitted a small auxiliary cylinder. The rear end of the piston-rod entered this cylinder, but 'O' ring seals prevented the passage of any air from the reservoir into the auxiliary cylinder. To the end of the piston-rod was fitted a circular piston, which was a good sliding fit within the auxiliary cylinder.

B.3 A transfer pipe was fitted between the reservoir and the auxiliary cylinder, and in this pipe was fitted an electro-pneumatic A.C. operated valve.

B.4 Through the end of the auxiliary cylinder furthest from the reservoir passed a large screwed rod, which carried a hand wheel at its outer end. The purpose of this was to engage with the piston, and push it, and hence the piston-rod and head, forward after the gun had been fired and thus seal off the reservoir from the gun barrel.

B.5 In operation, the piston-rod was moved into its forward position by means of the wheel and screw, and then the reservoir was charged to the required pressure. The air inside the cylinder, acting on the rearward face of the piston-rod valve-head, kept this in firm contact with the cone, and so effected a leak-proof joint. The action of pressing the gun firing button was to open the solenoid valve, and thus allow air to enter, by means of the transfer pipe, the auxiliary cylinder, where it acted upon the piston. Since the effective area of the piston was greater than that of the rear face of the piston-rod head, the whole moved backwards, thus breaking the seal and allowing the air in the reservoir to act upon the projectile.

B.6 Theoretically this was a very simple system, and had many advantages over the bursting discs. Any required pressure in the reservoir could be catered for without having to determine the necessary disc thickness; stocks of fairly expensive discs were unnecessary, and the system was safer. Once the piston had been pushed forwards by means of the wheel and screw, the gun could not be fired until this screw had been run back again so as to give travel to the piston. Thus, by making the removal of the restraint imposed by the screw a part of the firing procedure, i.e. not removing it until the start of the firing countdown, all possibility of a premature firing was removed.

B.7 Unfortunately, the system foundered on the lack of ability to arrest the piston once it had started to move. The original scheme was that, as soon as the piston moved a small amount, ports were opened which allowed the air to pass from one side of the piston to the other, so building up a back pressure which would bring the piston and rod to rest. In the event, the piston moved so rapidly that there was insufficient time to build up any pressure, and the piston struck the end of the auxiliary cylinder.

B.8 The ports were then sealed off, and the volume of the auxiliary cylinder behind the piston was considerably reduced so that, as the piston moved, the air behind it was compressed sufficiently to act as a buffer and bring it to rest. This too failed to work satisfactorily. Although a good fit in the auxiliary cylinder, the piston had to have some clearance, and, when taken over the whole diameter (over 10 inches) the effect was equivalent to an appreciable sized hole. Thus insufficient pressure was built up due to this leakage, and again the piston struck the end of the auxiliary cylinder.

B.9 Finally, the piston was grooved, and an 'O' ring seal inserted in this groove. This prevented any leakage back past the piston, and the system worked well up to the maximum pressure required. Unfortunately, due, it was presumed, to the high speed of movement of the piston, the life of the 'O' ring seal in it was very short, and after a comparatively few shots the gun started to behave erratically. Thus, for the reasons already outlined, work on the internal valve was stopped, and a change back to discs was made.

### Appendix C

#### SAFETY TESTS

C.1 As mentioned in para. 4.6.4., a series of safety tests was done. The objects of the tests were, (a) to see if a premature burst of one of the discs in the double-disc firing system would result in a dangerous build-up of static pressure in the building, (b) to see if a premature burst of a disc would raise the noise level in the building to an uncomfortable level, and (c) to try and make an estimate of the chances of a premature burst occurring.

C.2 These safety tests were done when locally produced discs were being used, but the present use of bought-out discs does not invalidate the tests in any way. Where necessary, however, the results have been interpreted in the light of present procedures.

C.3 As described in para. 4.6.2, should a disc burst prematurely, the contents of the reservoir would be discharged, not down the barrel of the gun, but into the building through a set of holes in the breach block and outer casing. Further, if this burst occurred at the instant of rotating the breach, a condition exists where there is a channel for air from the reservoir into the building directly through the part-turned breach.

C.4 Two 30 swg discs were inserted into the disc holder, and the interspace and reservoir pressures were calculated in the normal way. With the breach in the "LOAD" position, the gun was fired from outside the building, the doors and windows being closed. (Normally this would be impossible, but for the purpose of these tests the safety devices were shorted out.) A pressure transducer, feeding to a Cintel recorder, was mounted in the building at the operator's position. The test was repeated using two 24 swg discs, thus giving a greatly increased pressure in the reservoir. These two tests were then repeated with the breach part-way between "LOAD" and "FIRE", the position being chosen such that the through passage for air, noted above, was a maximum.

C.5 Using two 30 swg discs, the pressure in the reservoir was  $101 \text{ lb/in}^2$ . Both with the breach in the "LOAD" position, and also in a position between "LOAD" and "FIRE", no pressure rise in the building could be detected. The windows, although closed, were not latched, so that even a slight pressure rise could be expected to push them open slightly, but this did not occur. In the latter test, it was expected that the force of the air might spin the breach block, with consequent possible harm to the operator who would, at that instant,

be rotating the breach. There was, however, no movement whatsoever of the breach.

C.6 Using two 24 swg discs, the pressure in the reservoir was  $183 \text{ lb/in}^2$ . With the breach in either position, any pressure rise in the building could scarcely be detected on the recorder, and a maximum figure for such a rise would be  $0.15 \text{ lb/in}^2$ . One window opened very slightly and very gently, but since its area is over  $900 \text{ in}^2$  and a force of only 2 lb was required to push it open, this is not regarded as being of any consequence.

C.7 The meter used for the noise level tests was not of the recording type, and, as the noise level decreased, had to be switched manually from range to range. Thus it was necessary for the operator to be in the building during the test, and this was regarded as being acceptable because of the low pressure increases recorded in the previous tests. In the whole series therefore, the gun was fired from within the building, the operator being protected by the wearing of ear defenders. In addition to measuring the peak noise-level, in most of the tests a record was made of the duration of noise above an arbitrarily chosen level of 70 db. The results obtained were as follows:-

Breach in "LOAD" position

<u>Reservoir pressure</u> <u>lb/in<sup>2</sup></u>	<u>Peak noise level</u> <u>db i.e. <math>0.0002 \text{ dyne/cm}^2</math></u>	<u>Time for noise level</u> <u>to fall to 70 db</u>
184	Greater than 135	not measured
102	130	not measured
76	130	35 seconds
42	120	28 seconds

Breach between "LOAD" and "FIRE"

<u>Reservoir pressure</u> <u>lb/in<sup>2</sup></u>	<u>Peak noise level</u> <u>db i.e. <math>0.0002 \text{ dyne/cm}^2</math></u>	<u>Time for noise level</u> <u>to fall to 70 db</u>
182	Greater than 135	29 seconds
102	130	20 seconds
76	125	28 seconds
42	125	14 seconds

C.8 For the endurance tests, different thicknesses of discs were used in three successive tests, and in each case the interspace and reservoir pressures were calculated in the normal way for the maximum pressure case. On reaching the required pressures, the compressor was switched off, and the whole system left for a period of 1 hour from completion of charging. In no case during this time did any of the discs fracture. At the end of the period the disc holder was removed from the gun and the discs, which had been carefully marked before assembly, were examined. In no case was there the slightest sign of slipping of the discs, nor any undue distortion of them.

C.9 No attempt was made during these tests to simulate the effects of repeated loading and unloading of the discs, since this would not happen in practice. If, during the course of a test, pressure was applied to the discs, but for any reason the gun was not operated and the pressure was released, then it would be standard procedure to fit new discs before recharging the system.

C.10 There are three ways in which a premature burst can occur, (a) by the operator selecting inappropriate discs for the pressure to be used, (b) by the operator failing to turn off the right taps at the right time and (c) due to a batch of discs failing at only 70% of their nominal burst value, since no disc is ever subjected to a pressure in excess of this. In the case of (a), each disc is stamped with its nominal bursting value and, with reasonable care, no trouble should be experienced. The task of selecting and inserting the appropriate discs is one that is never delegated, but always done by the officer-in-charge. In the case of (b), the rate of pressure increase in the system from the compressor is so slow that, with a responsible operator, the chance of any error should be ruled out. In the case of (c), the manufacturers guarantee each batch of discs to have a bursting value within very close limits of the nominal value.

C.11 Taking all these factors into account, it is concluded that:

(a) the chance of a premature burst is so small as to make it capable of being neglected,

(b) if a premature burst was to occur, there is no significant build-up of pressure in the gun building,

(c) if a premature burst was to occur, the resultant noise level, even when using the thinnest discs, is very much greater than the level of comfort, particularly when the length of time for which it operates is taken into account,

(d) because, however, of (a) above, it was felt that there was no necessity to insist that all occupants of the gun building wear ear-defenders throughout the charging, preparation, and firing procedures.

Table 1PREDICTED PERFORMANCE OF R.A.E. GUN

$$V_C = 151 (0.84 p_1 - 15)^{\frac{1}{2}} \text{ ft/sec}$$

$$V_a = R V_C$$

Reservoir pressure lb/in <sup>2</sup> gauge	Theoretical velocity ft/sec	Correction factor R	Predicted velocity ft/sec
50	950	0.71	675
100	1360	0.61	830
150	1675	0.54	905
200	1950	0.49	955
250	2180	0.45	980
300	2380	0.43	1025

Table 2ESTIMATION OF CORRECTION FACTOR FOR R.A.E. GUN

$$V_C = 151 (0.84 p_1 - 15)^{\frac{1}{2}} \text{ ft/sec}$$

Reservoir pressure lb/in <sup>2</sup> abs. $p_1$	Theoretical velocity ft/sec $V_C$	Actual velocity ft/sec $V_a$	Correction factor $V_a/V_C$ R
55	844	520	0.616
75	1045	660	0.632
95	1215	750	0.618
115	1360	810	0.596
135	1500	870	0.580
155	1620	910	0.561
175	1735	940	0.542

REFERENCES

<u>No.</u>	<u>Author</u>	<u>Title, etc.</u>
1		The design of aircraft transparencies for resistance against impact by birds and hailstones. R.A.E. Technical Note No. Mech. Eng. 106, 1952
2	D. C. Jenkins	An assessment of some possible types of apparatus for the study of bird impacts on aircraft wind-screens at high speed. R.A.E. Departmental Memo. No. Mech. Eng. 220, 1959
3	Kangas Pigman	Development of aircraft windshields to resist impact with birds in flight. C.A.A.T.D.C. Report, 1948



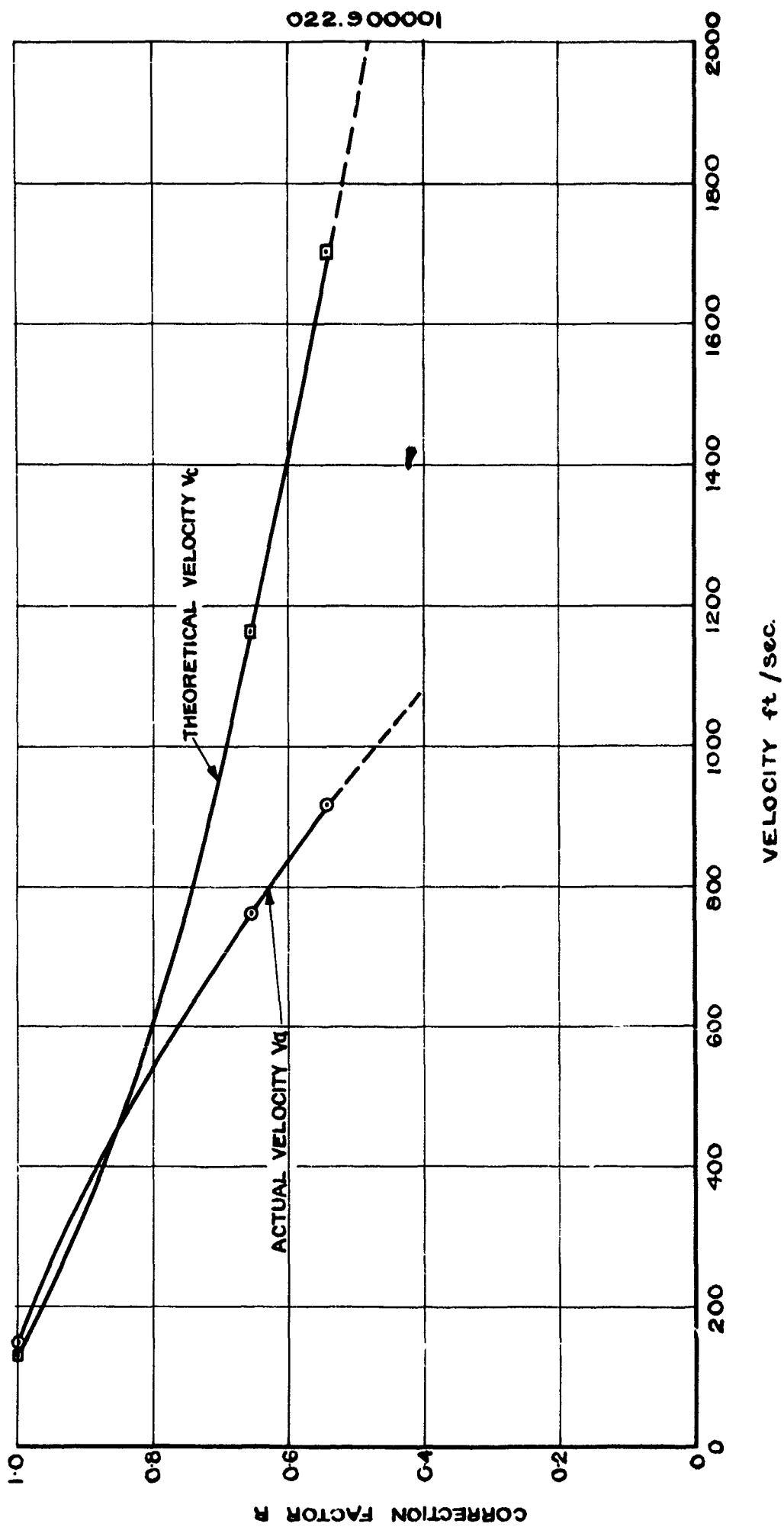
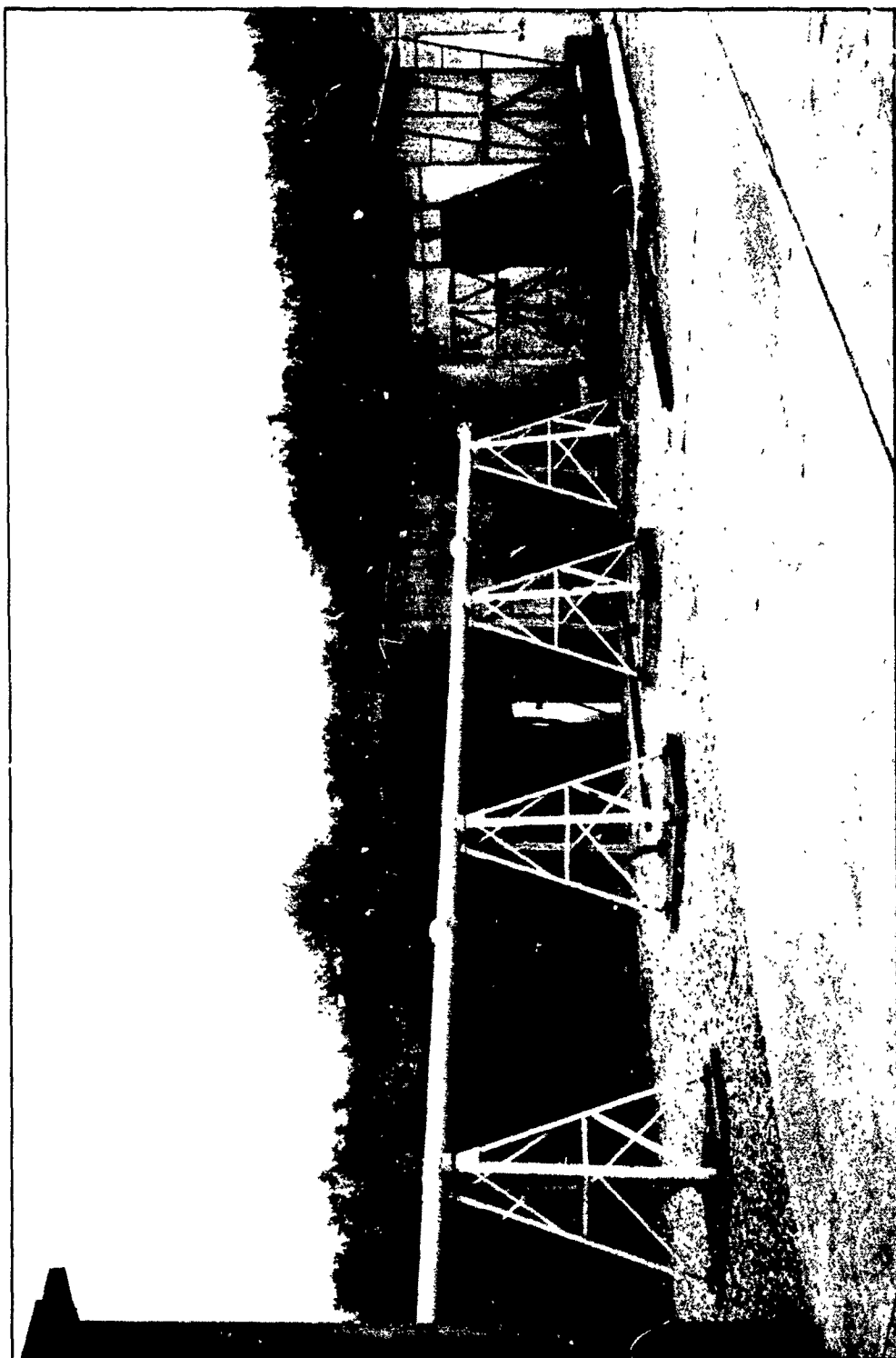


Fig.1

FIG.1 VARIATION OF CORRECTION FACTOR R WITH SPEED. C.A.A.T.D.C. GUN

**Fig.2**

Neg. No. C1519



**Fig.2 General view of gun barrel and target area**

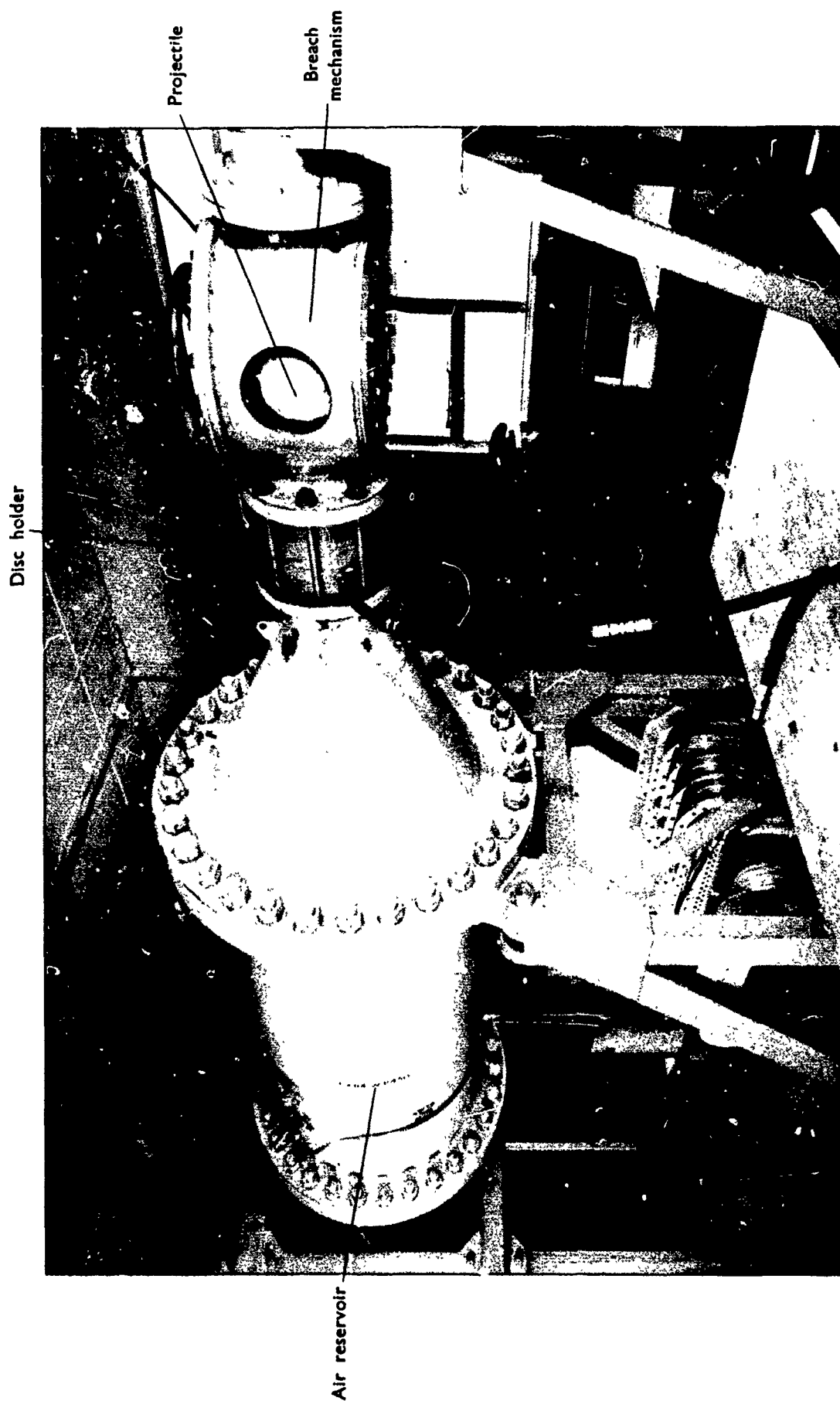


Fig.3 Reservoir end of the gun  
( Breach in the 'Load' position )

Fig.4

Neg. No. C1521

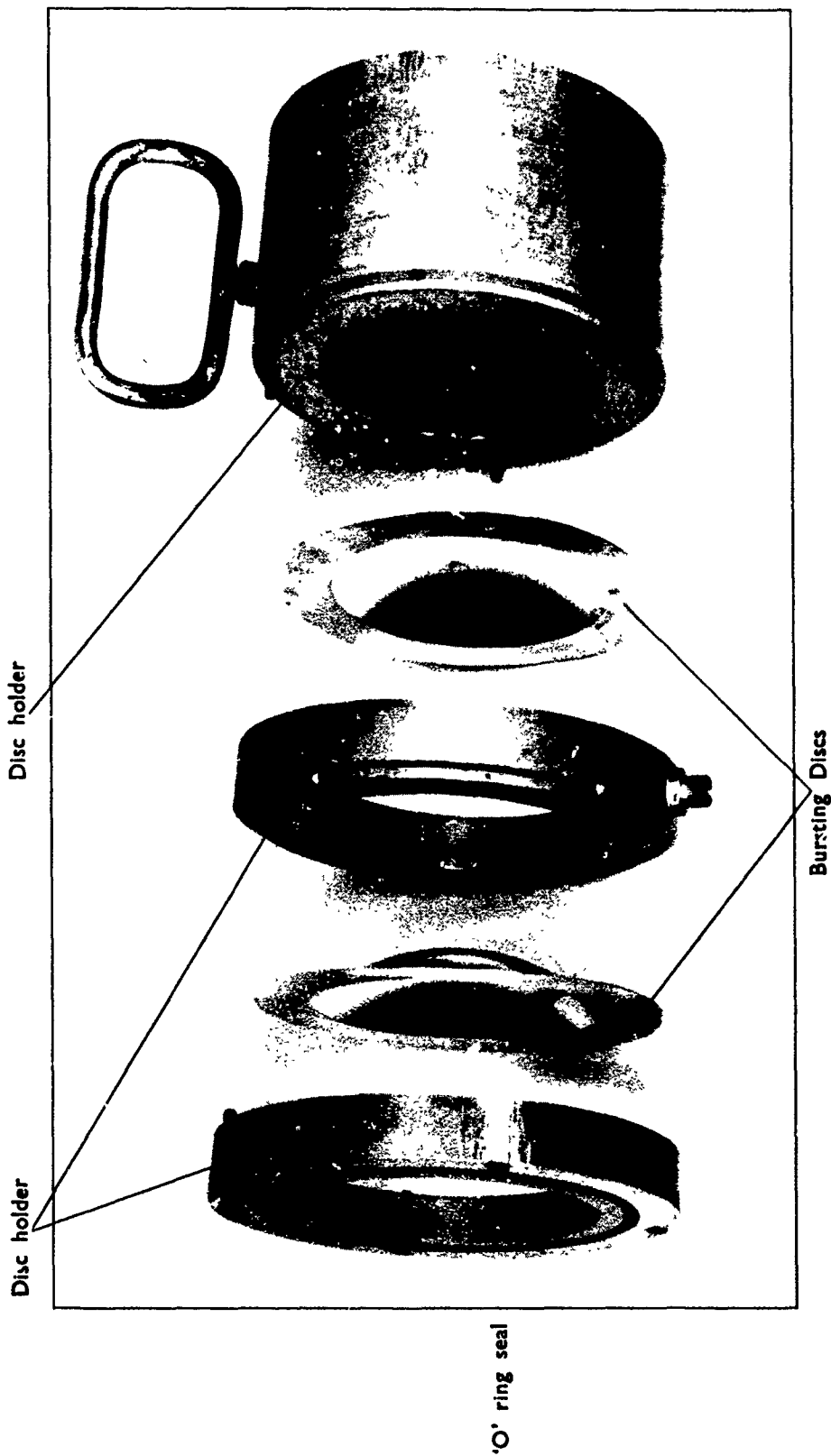


Fig.4 Components of bursting disc system

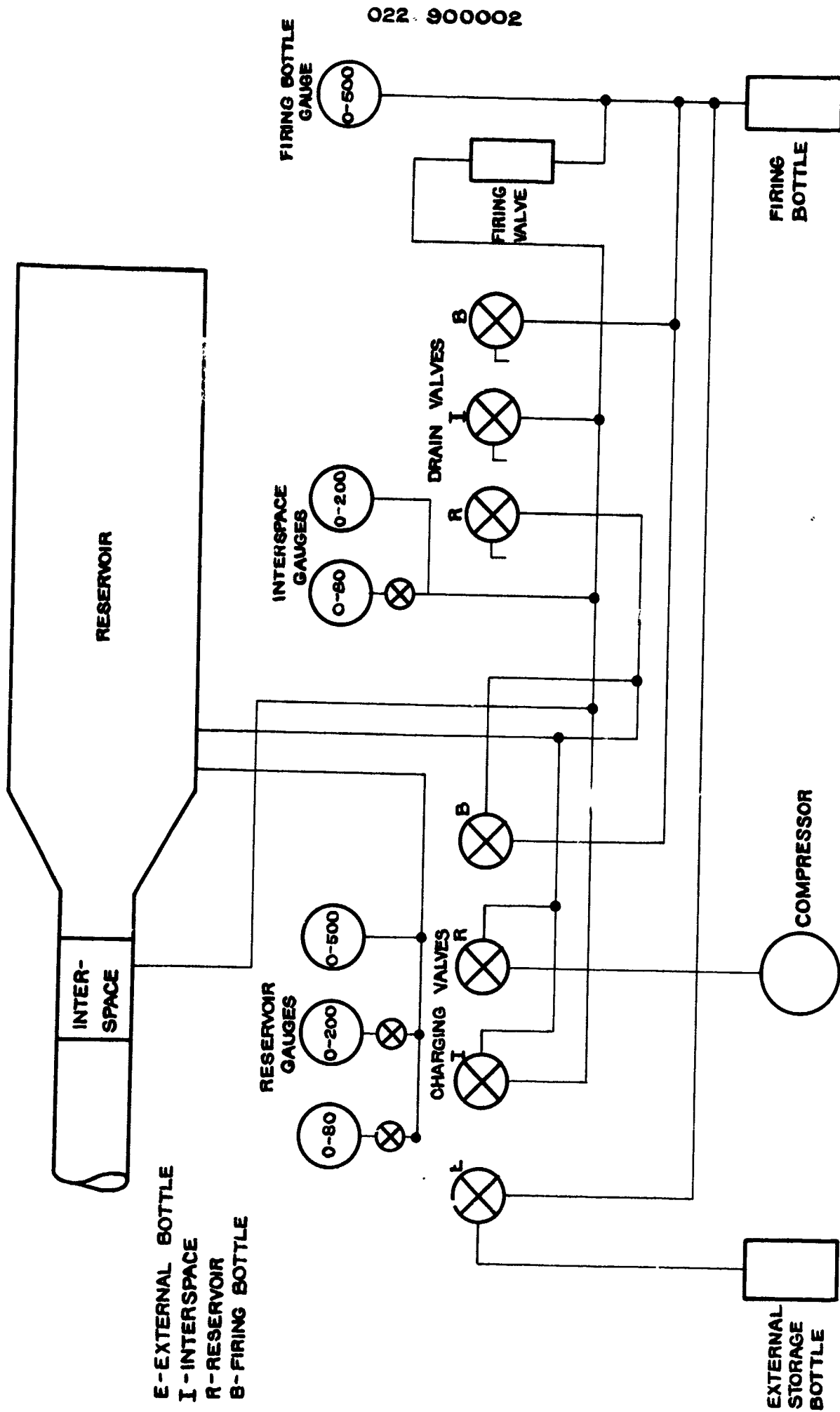


Fig.5

FIG.5 DIAGRAMMATIC ARRANGEMENT OF PNEUMATIC CIRCUIT

Fig.6

Neg. No. C1522

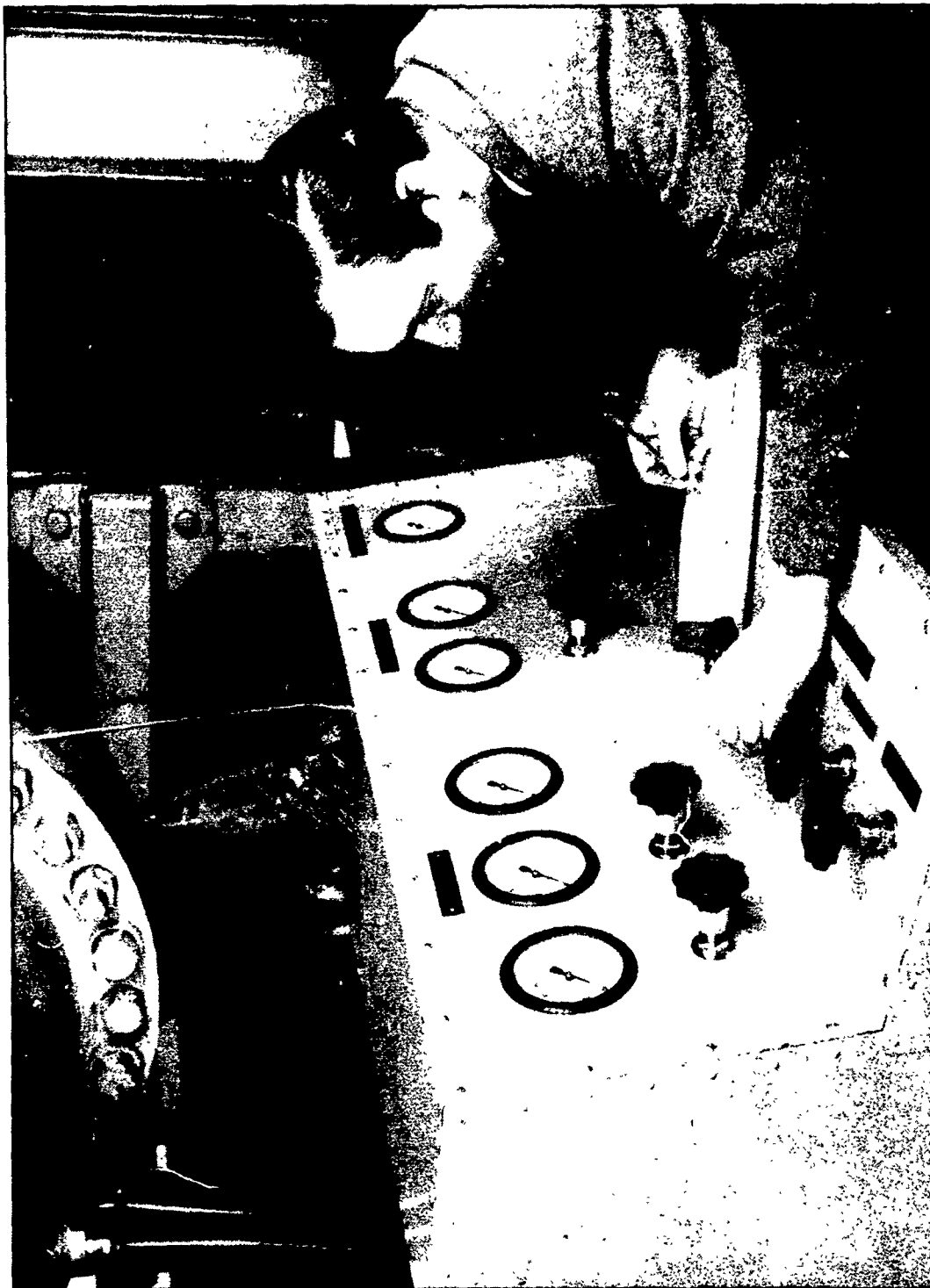


Fig.6 Control console

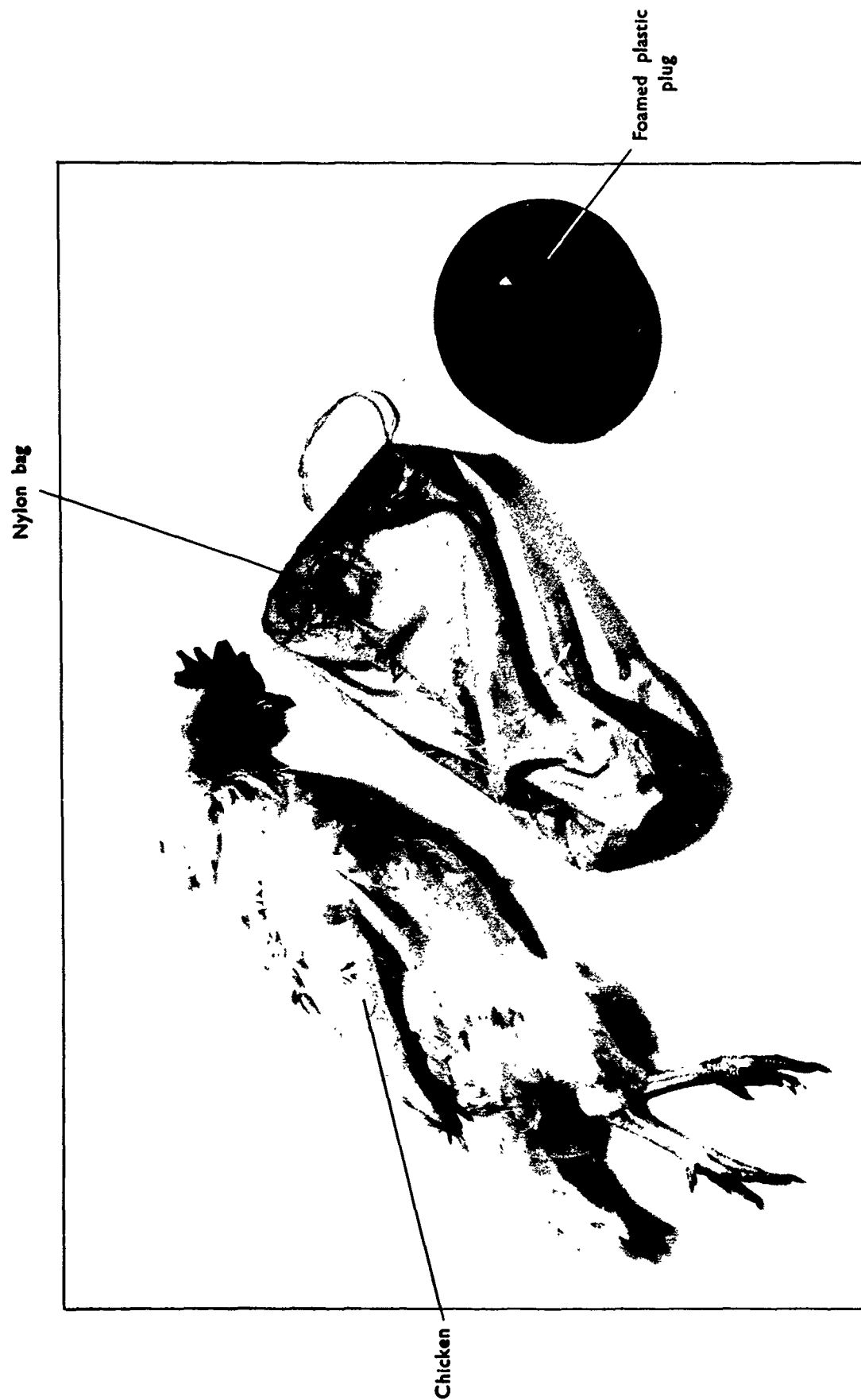
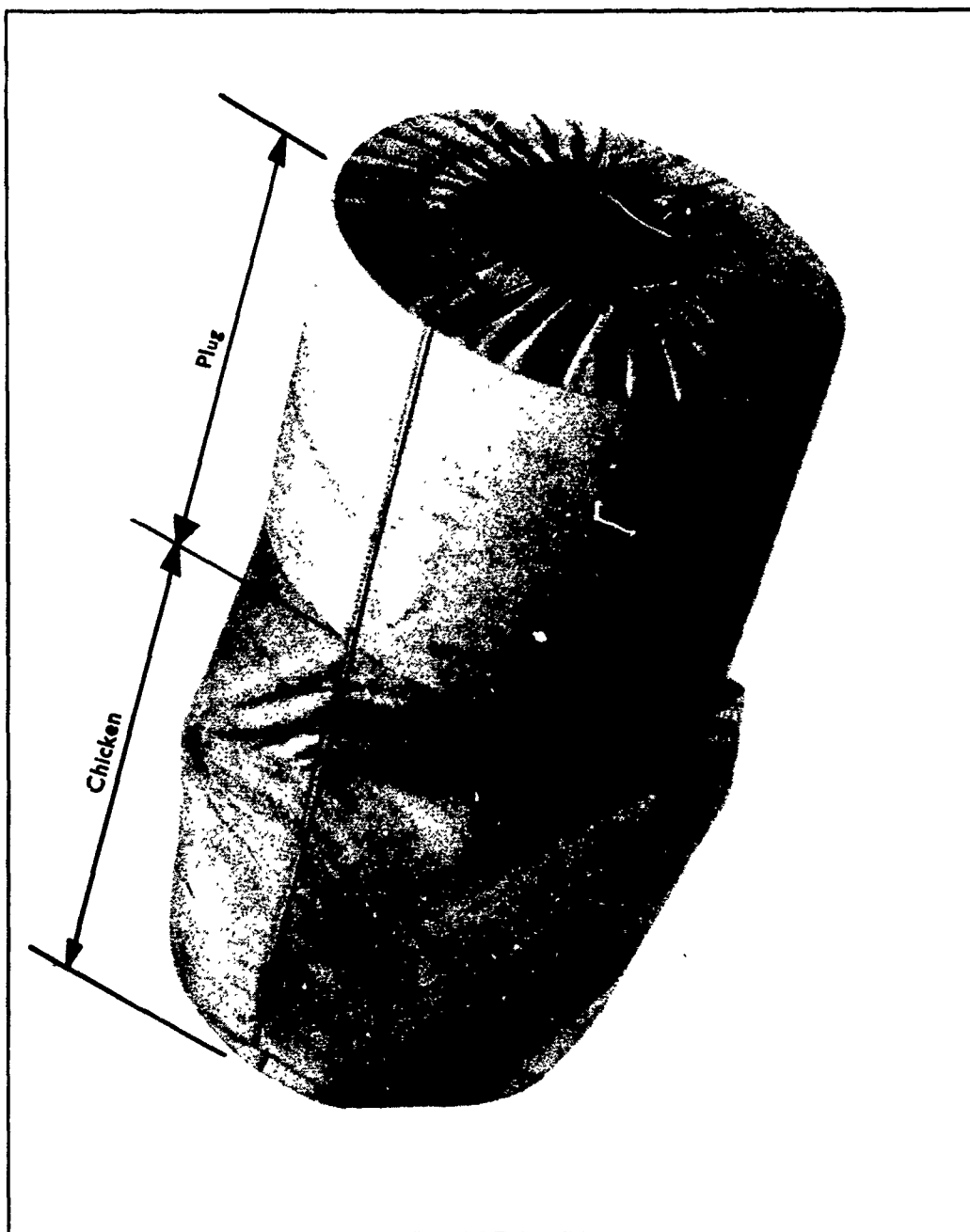


Fig.7 Components of standard 4lb projectile

**Fig.8**

Neg. No. C1524



**Fig.8 Completed standard 4lb projectile**



Contacts for break wires

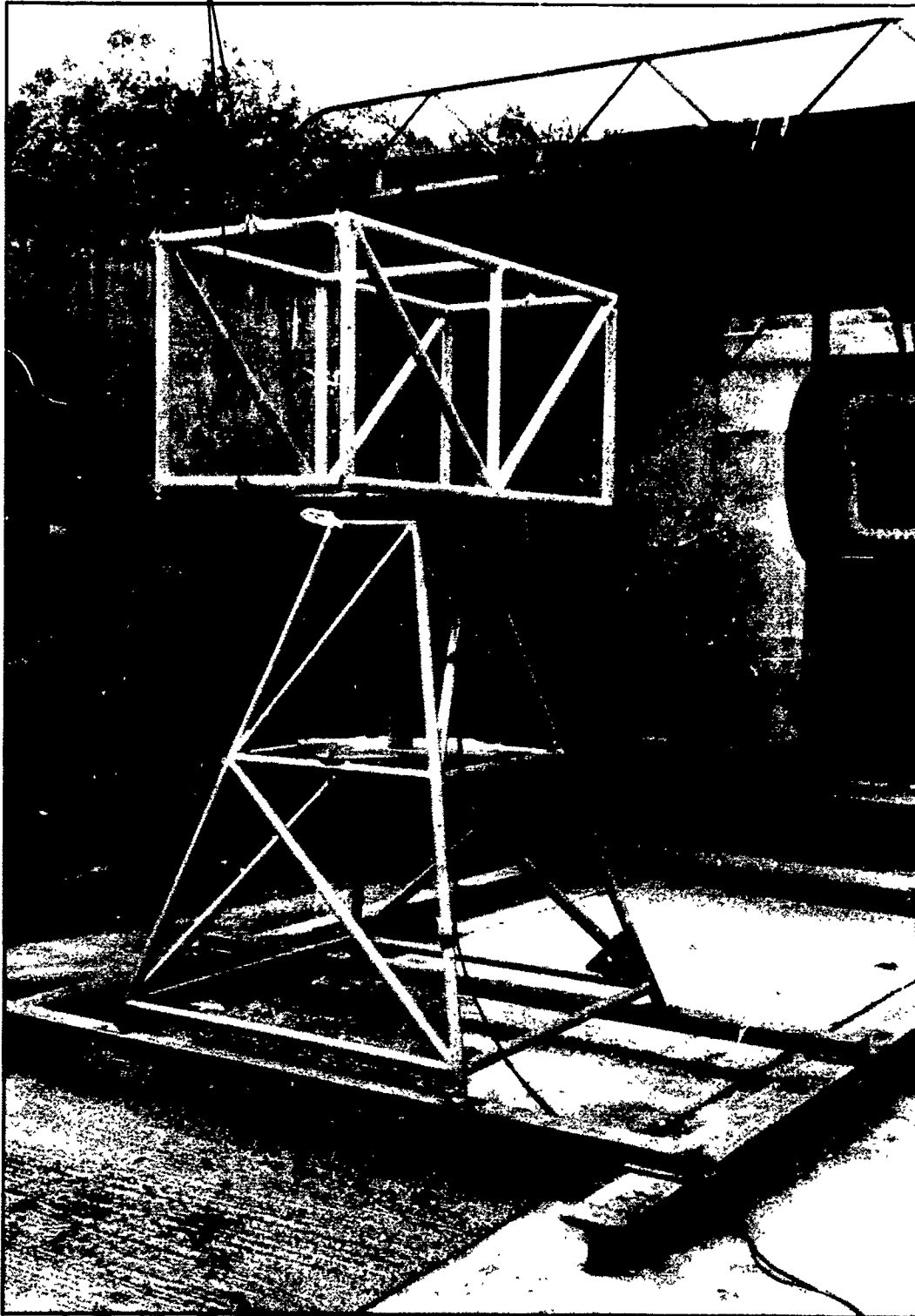


Fig.9 Timing stand

Fig.10

O22 900003

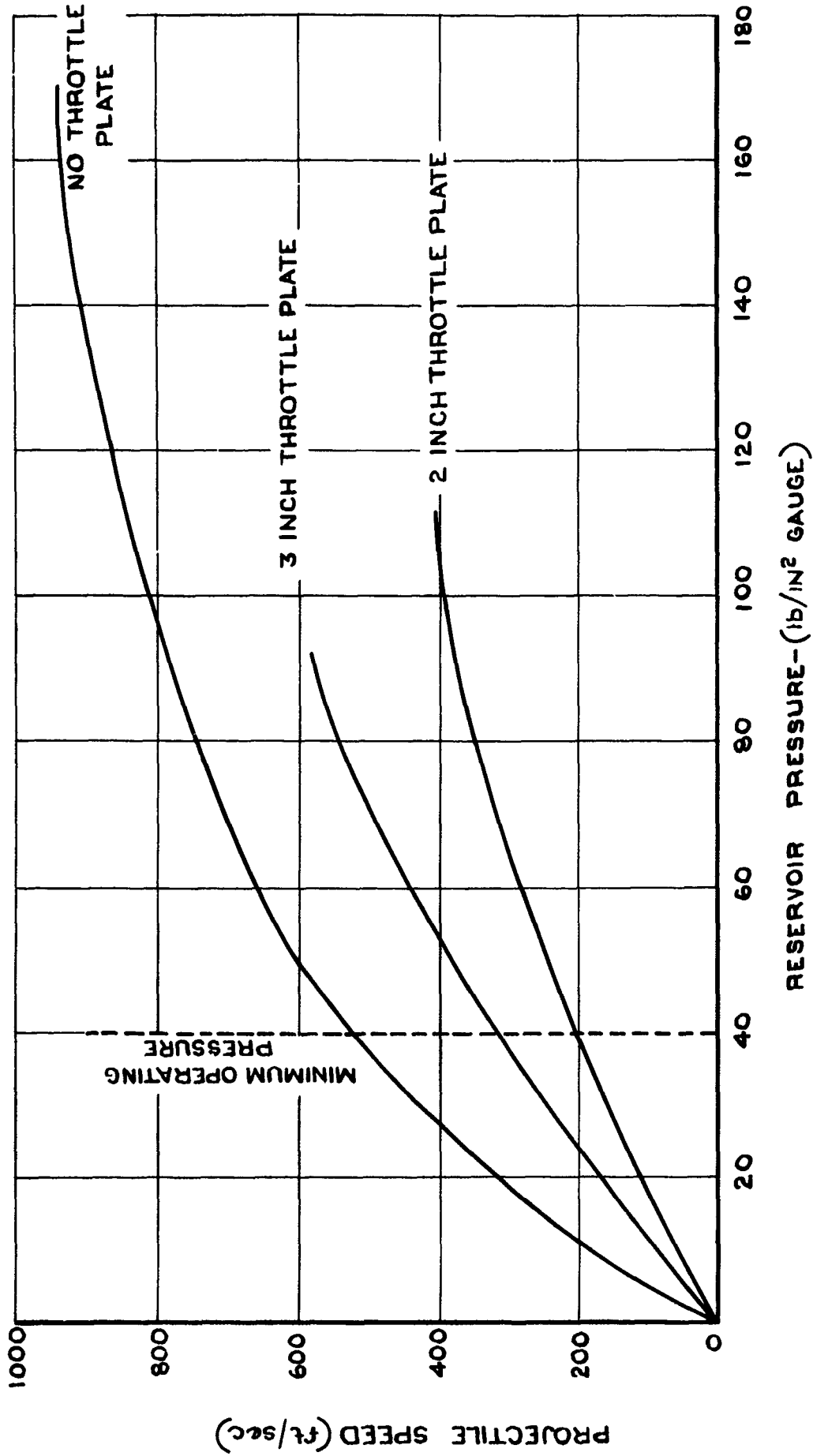


FIG.10. CALIBRATION CURVE FOR 4b PROJECTILE

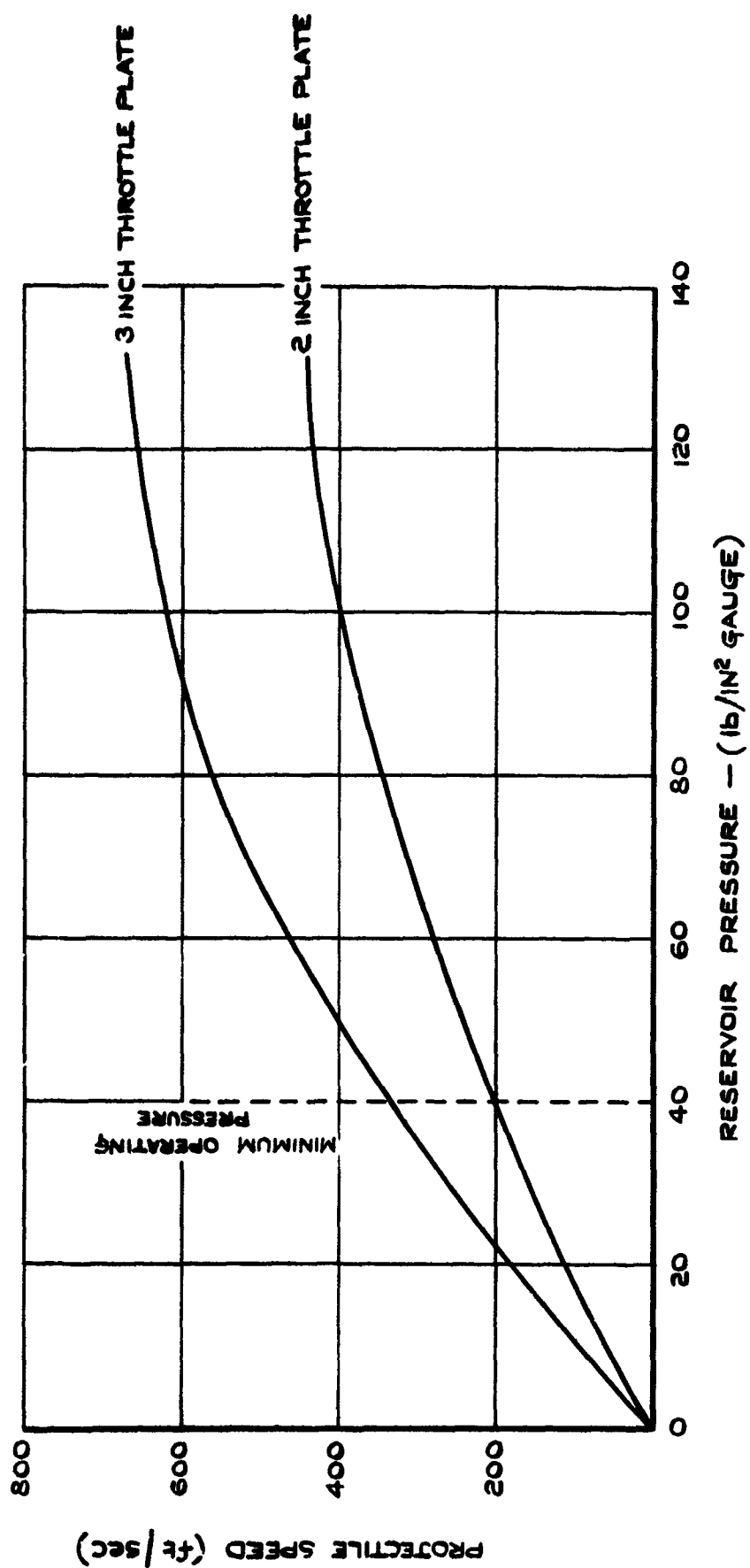


FIG.11 CALIBRATION CURVE FOR 2 1/2 lb PROJECTILE

Fig.12

022.900005

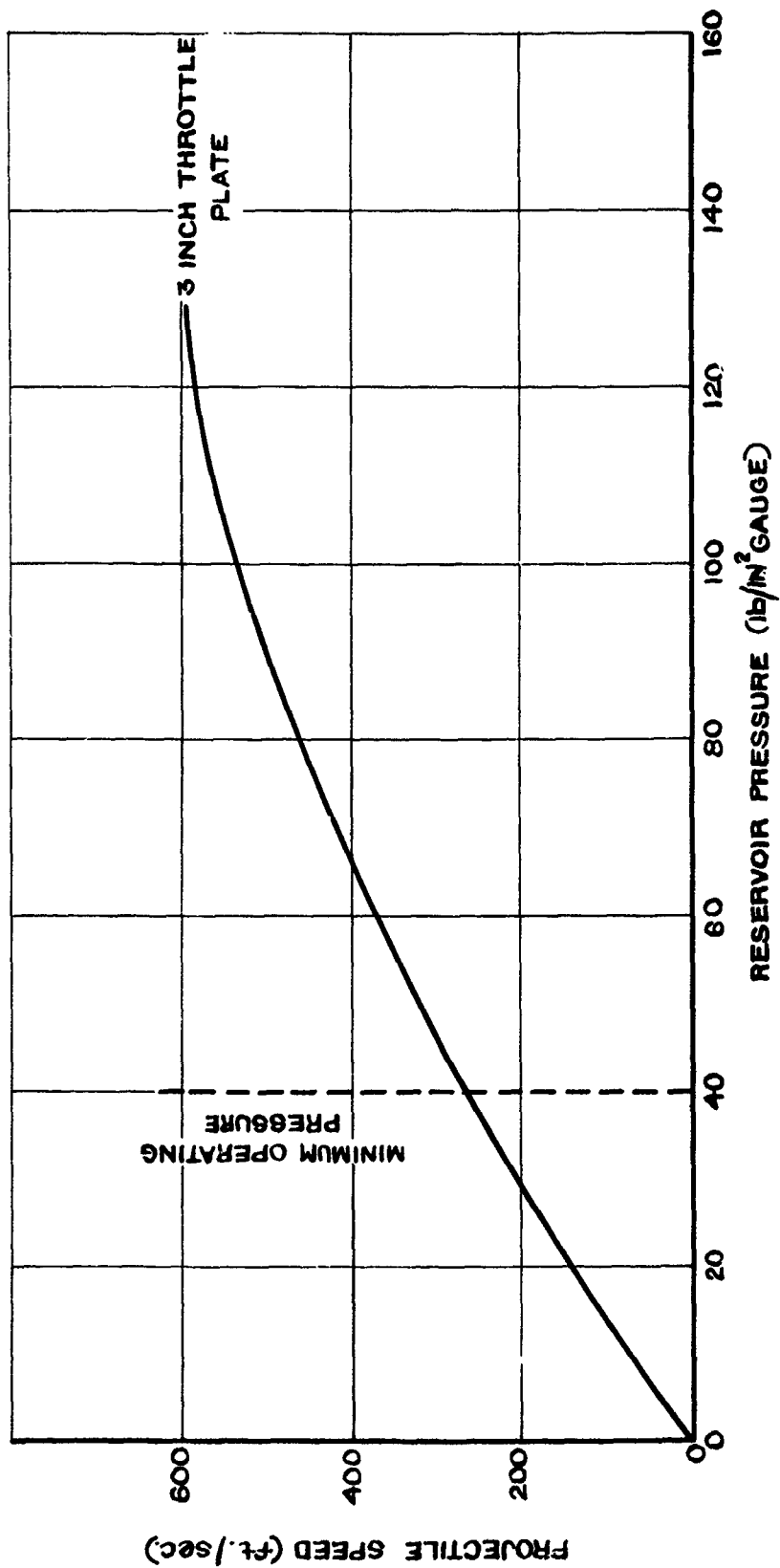


FIG.12 CALIBRATION CURVE FOR 11b. PROJECTILE

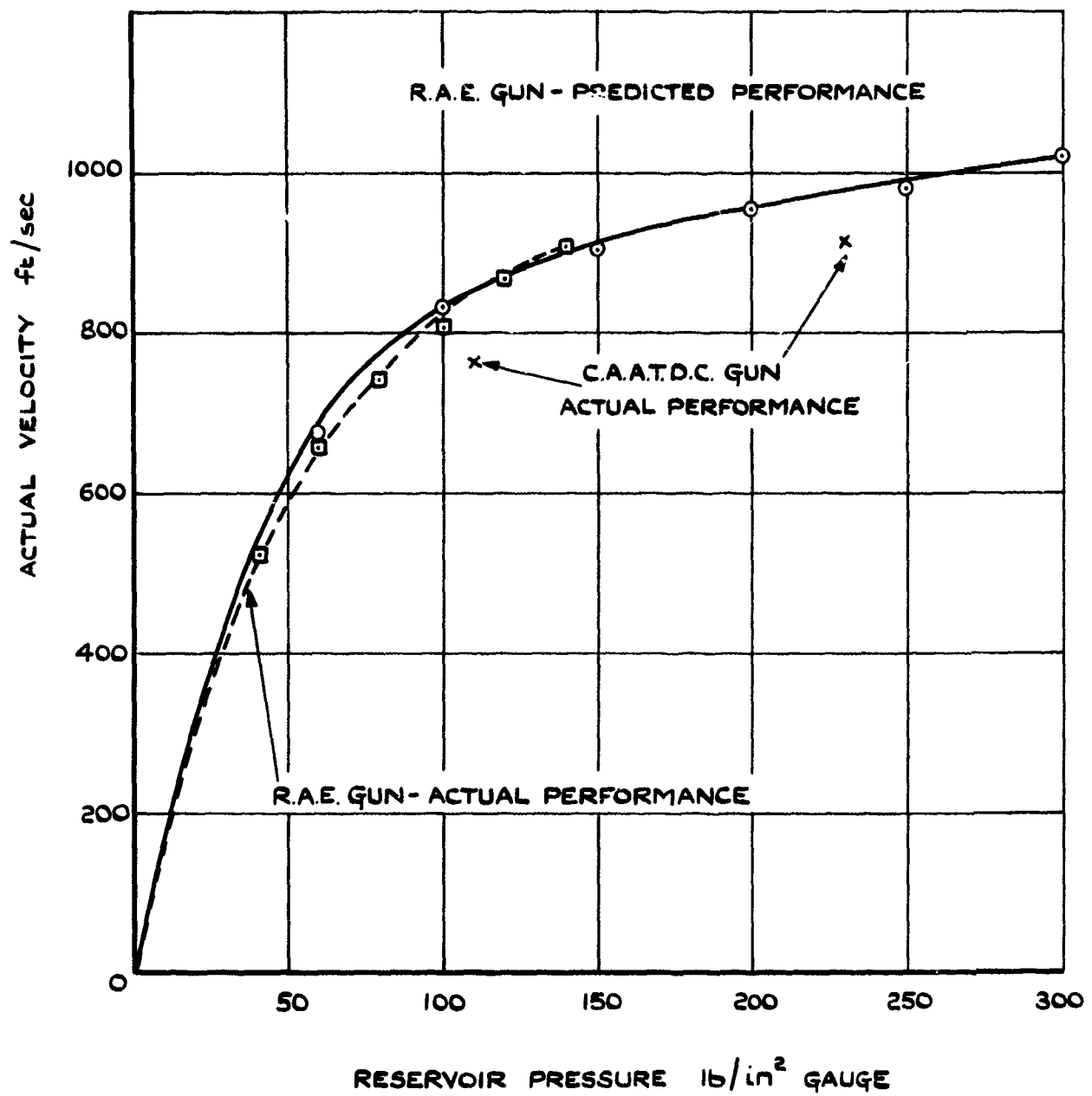


FIG. 13

Fig.14

022.900007

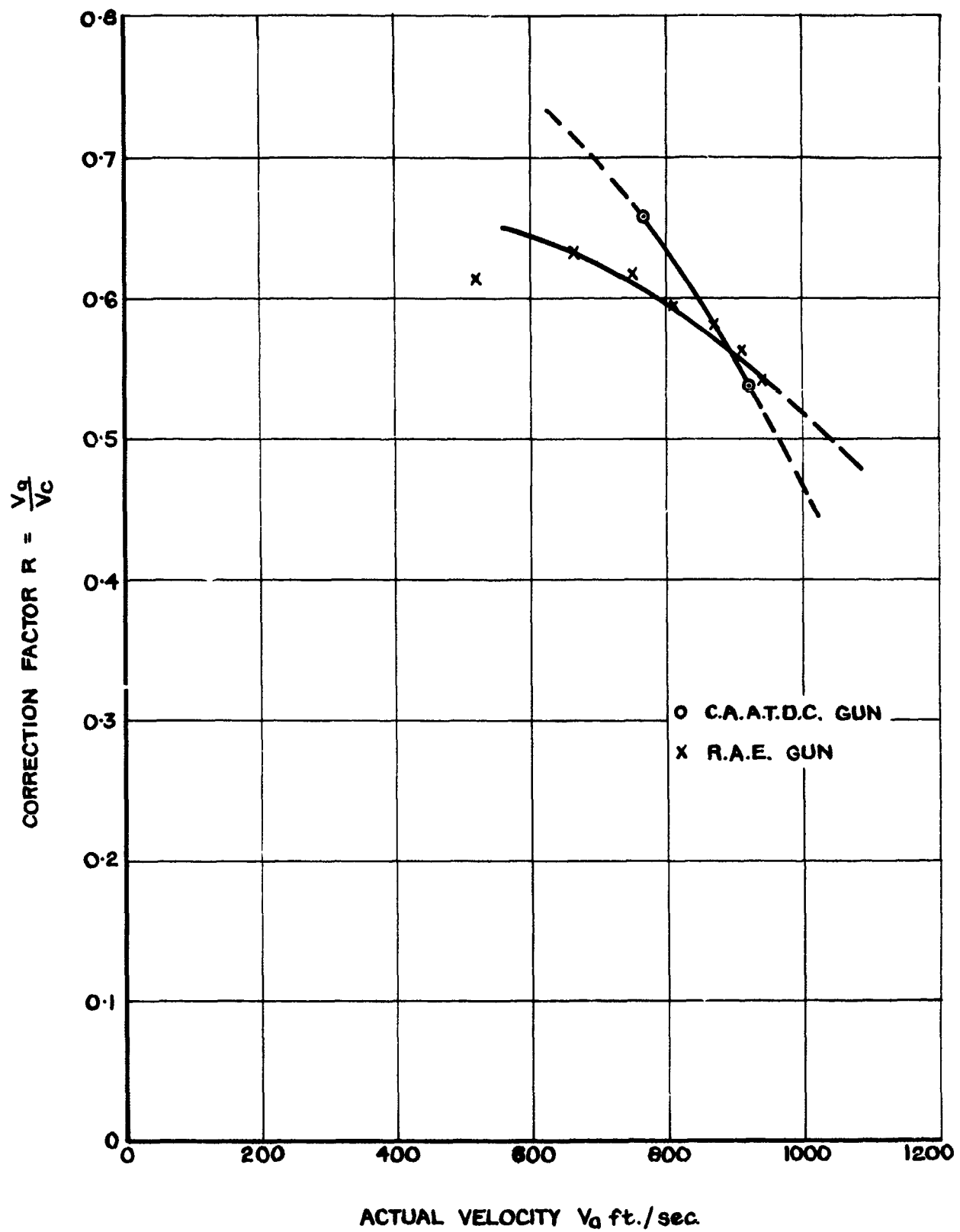


FIG.14 VARIATION OF CORRECTION FACTOR  
WITH ACTUAL VELOCITY

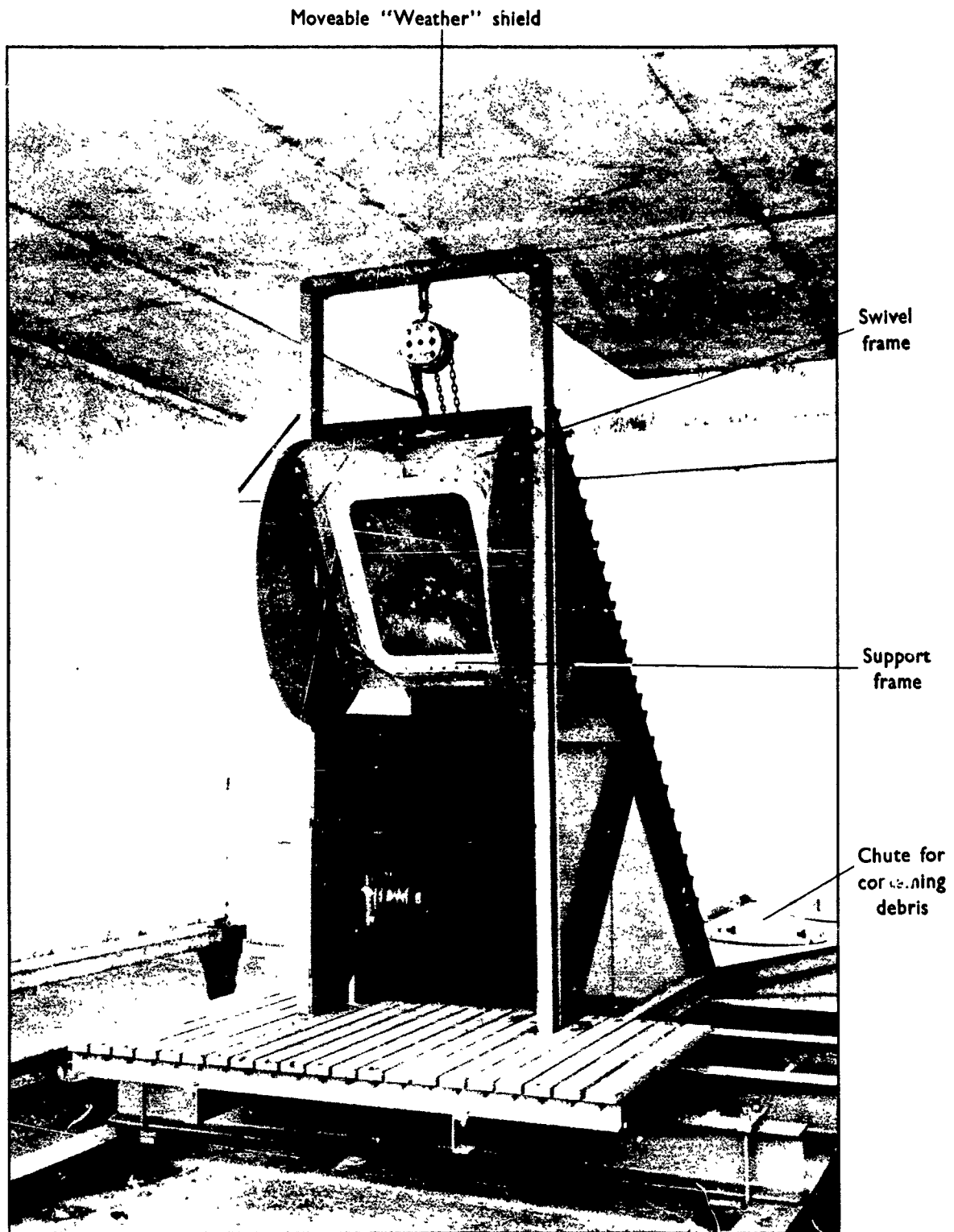


Fig.15 Target structure

(N.B. A steel test plate is in position where normally a glass, etc. panel would be positioned )

Fig.16

022.900008

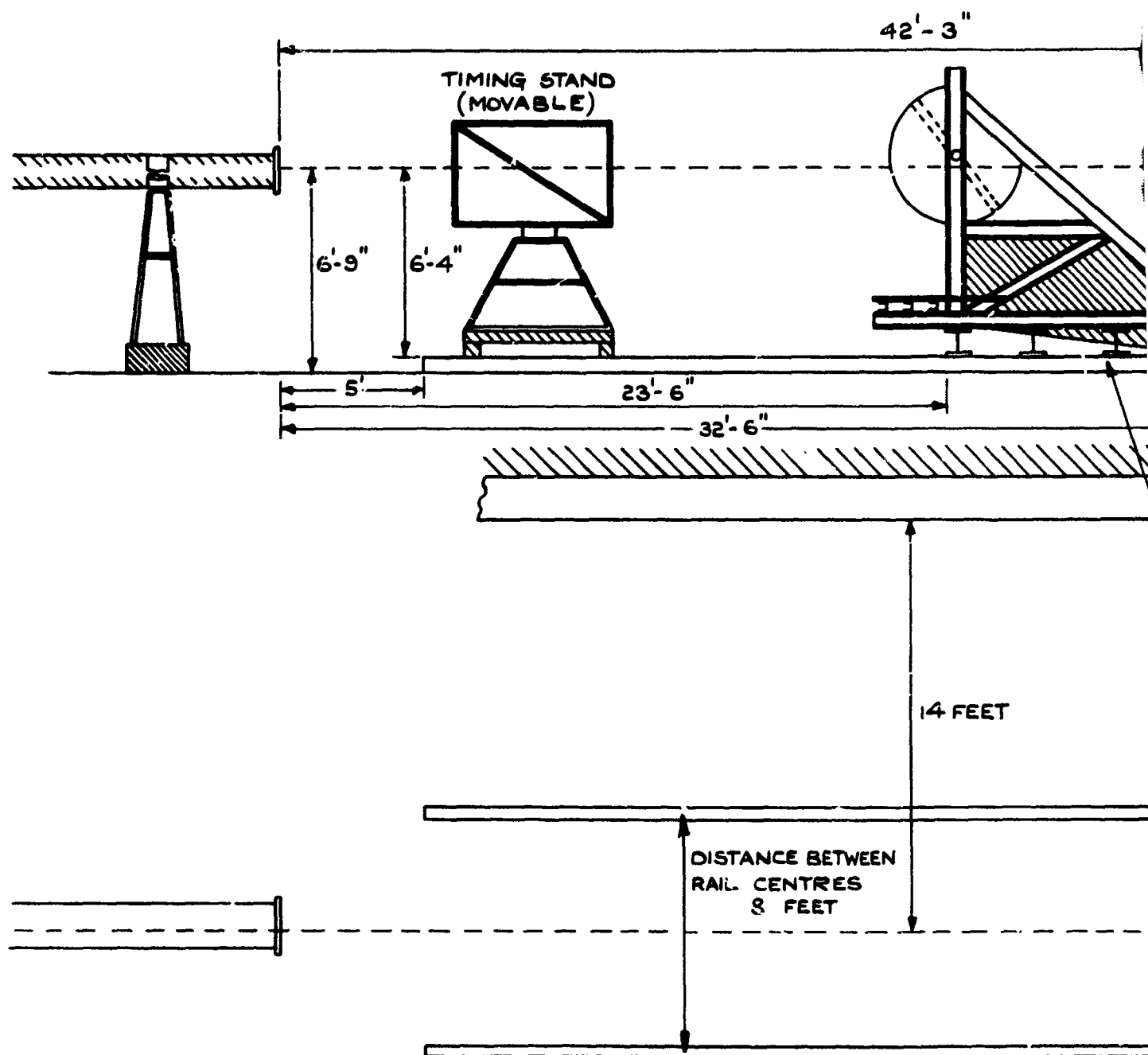
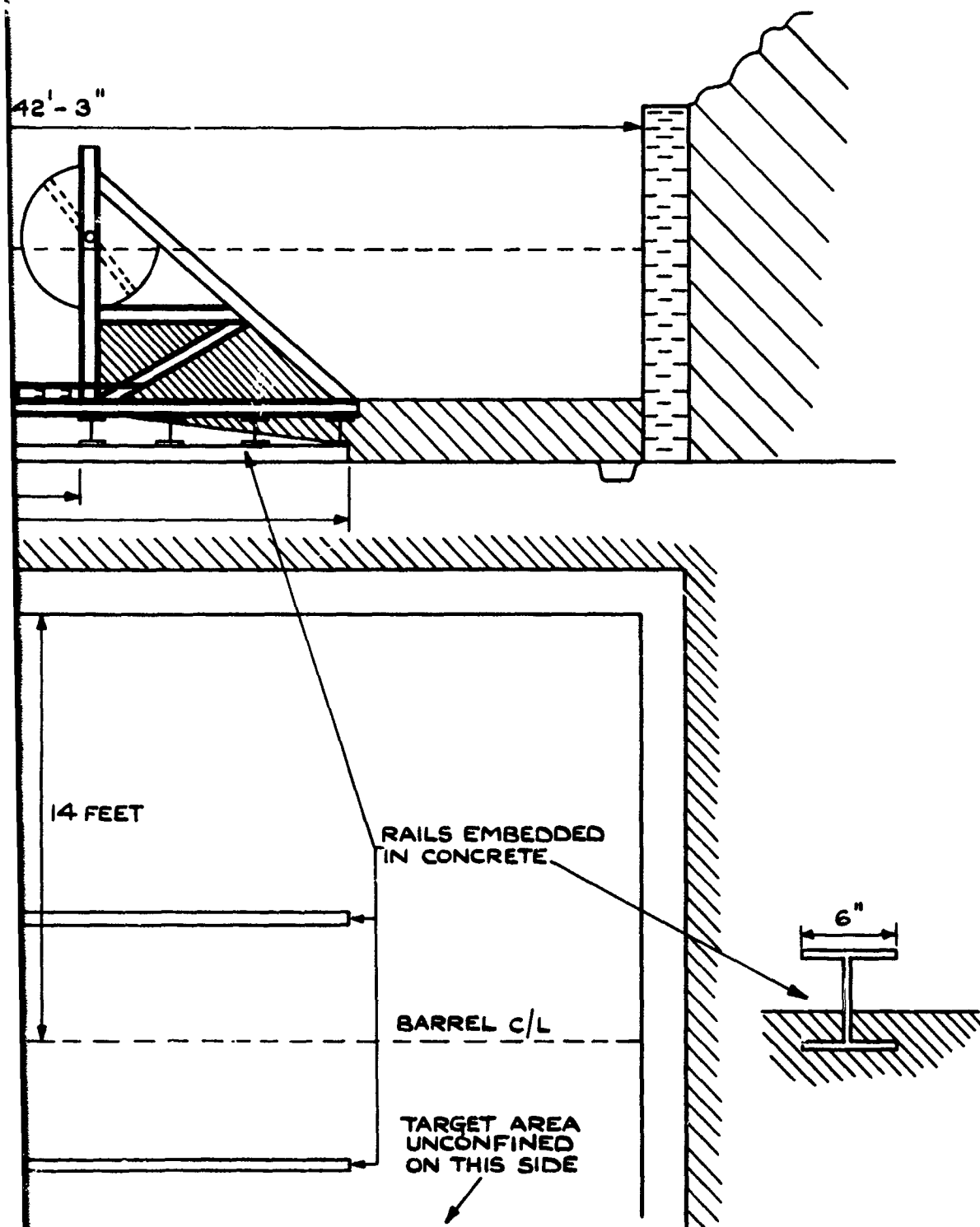


FIG.16  
BIRD IMPACT TEST FACILITY  
DETAILS OF TARGET AREA  
SHOWING WINDSCREEN TARGET ASSEMBLY  
AND TIMING STAND INSTALLED.





6  
ES FACILITY

ARGE AREA  
N TARGET ASSEMBLY  
ND INSTALLED.

Fig.17



Fig.17 Typical assembly of windscreen specimen

Fig.18

Neg. No. C1528

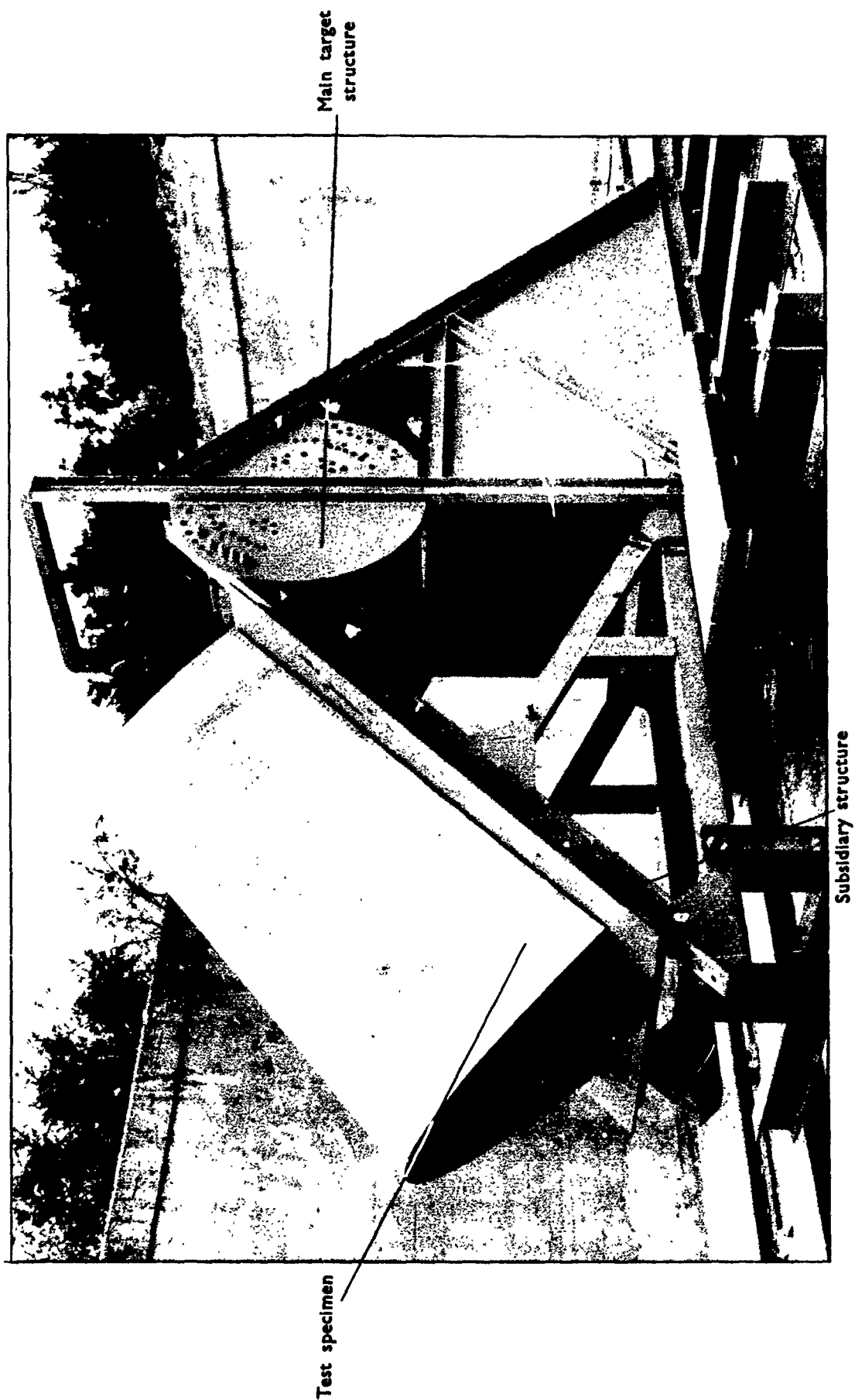


Fig.18 Typical assembly of wing section specimen

DETACHABLE ABSTRACT CARDS

<p>Perfect, D.A.</p> <p>623.421.7 : 598.2</p> <p>THE DEVELOPMENT OF A SMOOTH BORE GUN FOR THE PROJECTION OF BIRD CARCASSES</p> <p>Royal Aircraft Establishment Technical Report 66008 January 1966</p> <p>A smooth bore gun apparatus has been designed and developed for the projection of bird carcasses of up to 4 lb weight at stationary targets. The apparatus is intended to provide basic information, and also to provide a testing facility, for the design of aircraft windscreens capable of withstanding the impact of birds during flight.</p> <p>Full details are given of the design basis of the gun and its associated equipment, and of its present performance.</p>	<p>Perfect, D.A.</p> <p>623.421.7 : 598.2</p> <p>THE DEVELOPMENT OF A SMOOTH BORE GUN FOR THE PROJECTION OF BIRD CARCASSES</p> <p>Royal Aircraft Establishment Technical Report 66008 January 1966</p> <p>A smooth bore gun apparatus has been designed and developed for the projection of bird carcasses of up to 4 lb weight at stationary targets. The apparatus is intended to provide basic information, and also to provide a testing facility, for the design of aircraft windscreens capable of withstanding the impact of birds during flight.</p> <p>Full details are given of the design basis of the gun and its associated equipment, and of its present performance.</p>
<p>Perfect, D.A.</p> <p>623.421.7 : 598.2</p> <p>THE DEVELOPMENT OF A SMOOTH BORE GUN FOR THE PROJECTION OF BIRD CARCASSES</p> <p>Royal Aircraft Establishment Technical Report 66008 January 1966</p> <p>A smooth bore gun apparatus has been designed and developed for the projection of bird carcasses of up to 4 lb weight at stationary targets. The apparatus is intended to provide basic information, and also to provide a testing facility, for the design of aircraft windscreens capable of withstanding the impact of birds during flight.</p> <p>Full details are given of the design basis of the gun and its associated equipment, and of its present performance.</p>	<p>Perfect, D.A.</p> <p>623.421.7 : 598.2</p> <p>THE DEVELOPMENT OF A SMOOTH BORE GUN FOR THE PROJECTION OF BIRD CARCASSES</p> <p>Royal Aircraft Establishment Technical Report 66008 January 1966</p> <p>A smooth bore gun apparatus has been designed and developed for the projection of bird carcasses of up to 4 lb weight at stationary targets. The apparatus is intended to provide basic information, and also to provide a testing facility, for the design of aircraft windscreens capable of withstanding the impact of birds during flight.</p> <p>Full details are given of the design basis of the gun and its associated equipment, and of its present performance.</p>